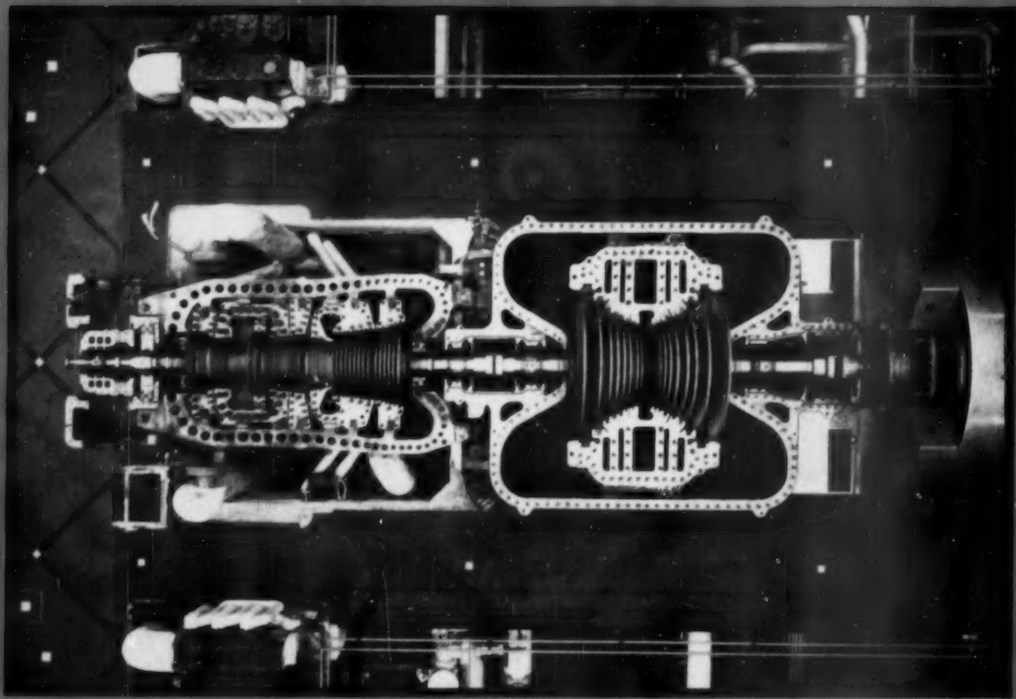
COMBUSTION

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

September 1954



Turbine Installation in an Italian Power Plant

COMBUSTION

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Feature Articles

Editorials

Departments

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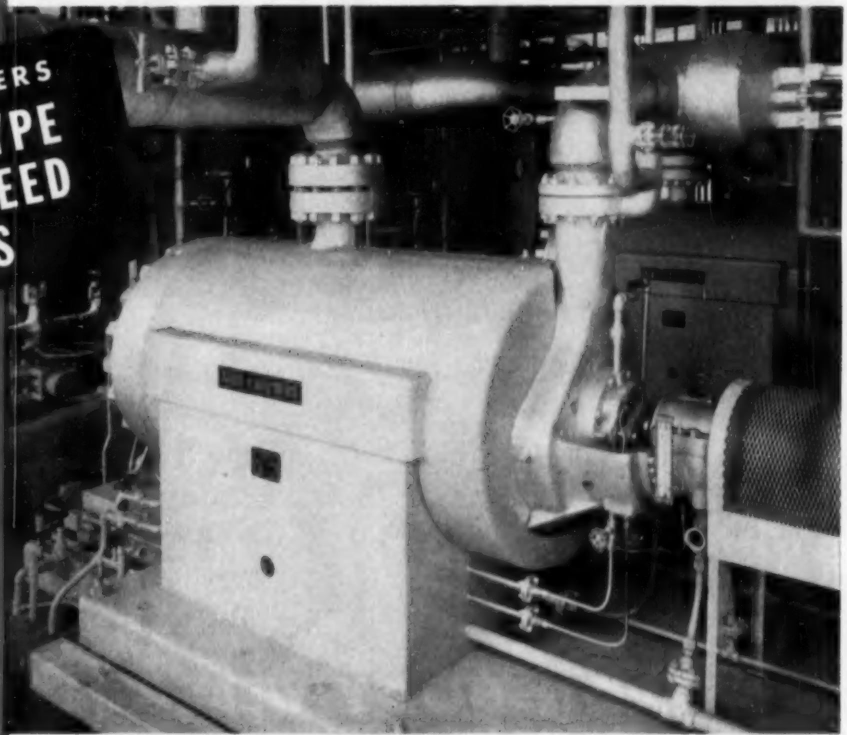
BPA

Printed in U. S. A.

ALLIS-CHALMERS
BARREL-TYPE
BOILER FEED
PUMPS



Preferred by
LOUISIANA
POWER &
LIGHT COMPANY
because

PERFORMANCE IS PROVED *in service*

PERFORMANCE RECORDS in power plants all over the country show *low maintenance, high efficiency*... that's one reason Allis-Chalmers boiler feed pumps were chosen for the Nine Mile Point Station of Louisiana Power & Light Company.

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Behind the A-C boiler feed pump stand many proved design features. For example: First stage has twin, single suction impellers to give low NPSH requirements for highest efficiency under fluctuating loads. Impellers mounted back to back balance axial forces without the need for a balancing drum. Expansion joint and seals are brought to the outside of the pump . . . they may be inspected often and worked on easily, if required.

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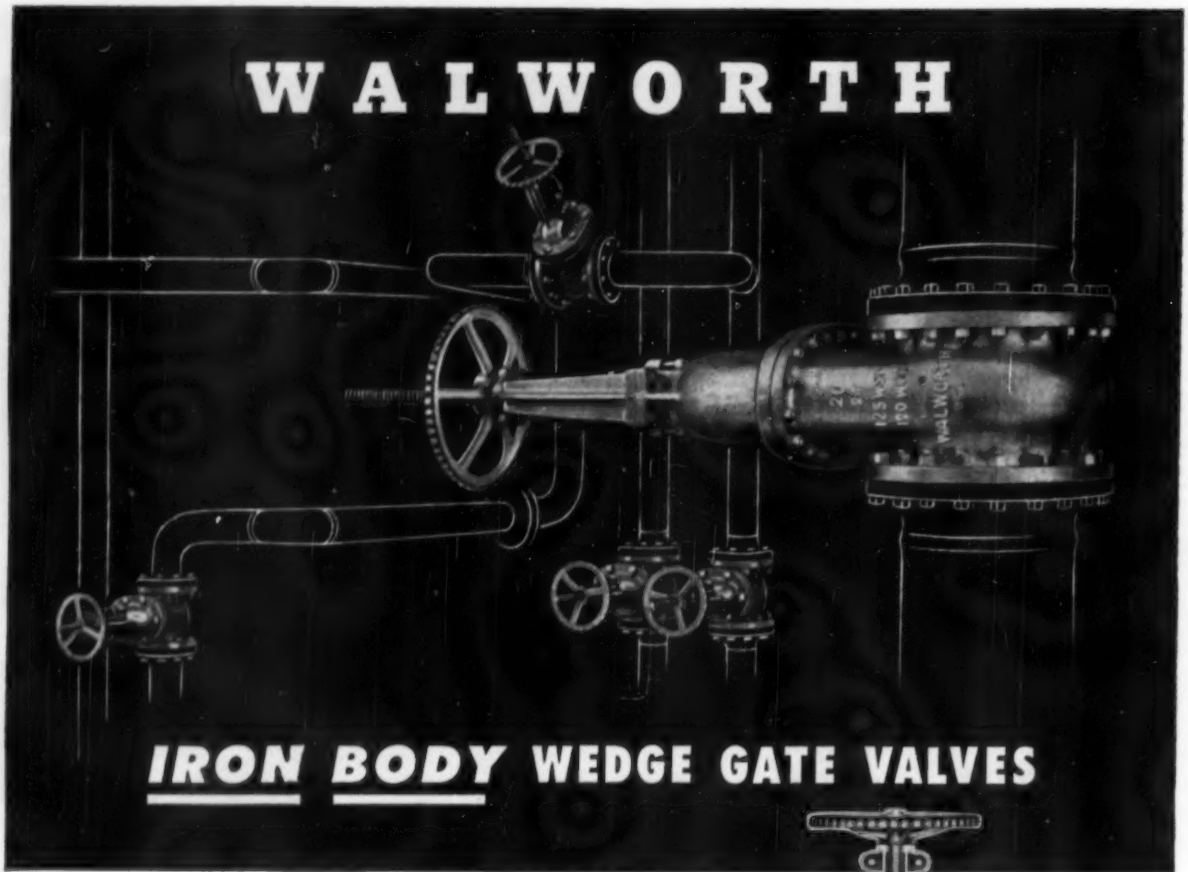
Allis-Chalmers can supply the complete pumping unit — pump, motor and control — all of coordinated design and manufacture. You get one responsibility — one guarantee of satisfaction.

Get complete information on Allis-Chalmers barrel-type boiler feed pumps. Call your Allis-Chalmers District Office or write Allis-Chalmers, Milwaukee 1, Wis., and ask for Bulletin 08B7899.

A-4328

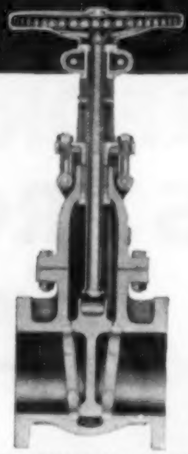
ALLIS-CHALMERS



Better because **...The entire valve, from handwheel to seat rings, is ruggedly constructed to withstand rough and frequent usage. Body, bonnet, and yoke are sturdy castings with large radius fillets. Dimensions and drilling of end flanges are in agreement with American Cast Iron Flange Standards. Stiffening ribs connect end flanges with the body neck to maintain a rigid connection with piping.**

A wide range of Walworth Iron Body Wedge Gate Valves is available—through your Walworth Distributor—from which you can choose the right type to meet your most exacting conditions. Saddle-type valves as small as ¼-inch; low pressure valves for water and gas pipelines up to 36 inches.

Whenever you need valves and fittings, choose from complete lines—in a variety of metals—manufactured by Walworth. For more information, see your Walworth Distributor or write: Walworth Company, General Offices, 60 East 42nd Street, New York 17, N. Y.



Walworth No. 726F OS&Y (Outside Screw and Yoke) Iron Body Wedge Gate Valve. OS&Y valves are recommended for services where it is desirable that the line fluid does not come in contact with the stem threads. Note the swing-type gland-eye-bolts for easy repacking. Sizes 2 to 30 inches.

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Manufacturers since 1842

valves . . . pipe fittings . . . pipe wrenches

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GOOD dogs and accurate shooting provide a reward no less keen than the satisfaction to be had in a Mitchell installation of critical piping. Save time and money on your next high-pressure or high-temperature job by enlisting the start-to-finish service of this 55-year-old organization of specialists.

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WESTPORT JOINT
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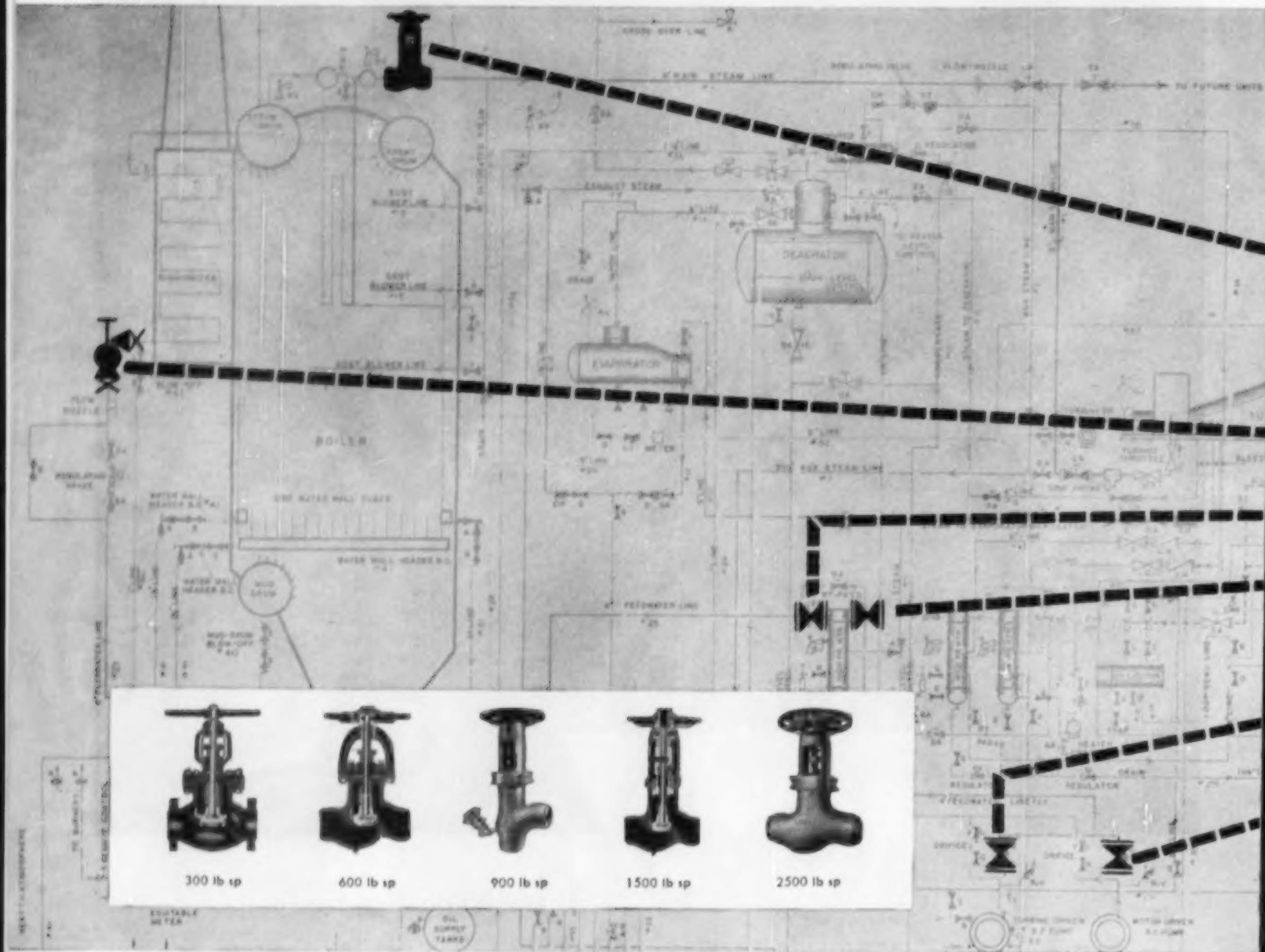
MITCHELL PIPING

SINCE 1899

PIPING FABRICATORS AND CONTRACTORS

What you should know about



In modern high pressure steam generating plants, economy, dependability and safety in "stop valve" applications can be improved by proper selection of valves. Edward, long a pioneer in high pressure-temperature steam control, has discovered many "stop valve" facts. Here are a few of the more important.

SELECTION POINTERS . . . that reduce installation costs and increase operating efficiency.

1 For flexibility in installation select stop valves that effect positive shut-off in any position. (Guided disks in all Edward cast steel globe and angle valves seat perfectly regardless of installation position.)

2 Angle valves in place of elbows reduce piping and installation costs and often improve operating convenience.

3 Using modern type globe or angle valves rather than gate valves on feedlines is recommended for tightnesss, repairability, adaptability and other reasons. (Edward bulletin DB-E6 explains all the advantages gained by using modern globe valves in central station boiler feedlines. Ask for it.)

4 Where Boiler Code requirements permit use of stop valve instead of non-return valve at steam discharge outlet, consider globe or angle valve for dependable shut off for boiler or main steam line hydrostatic tests.

5 For new installations, repairability of stop valves is a significant consideration. In spite of the greatest care in erection, damage to seating surfaces may take place during first months of operation. Selection of easily repaired valves will reduce costs. (Edward globe and angle valve seats can be relapped quickly and easily.)

6 Pressure drop is important in selecting stop valves. Turbulence tends to increase wear. (Edward globe and angle valves with their streamlined interiors reduce pressure drop and turbulence to a minimum. Catalog 12-H gives the complete story.)

7 On large high pressure valves which are closed or opened infrequently, avoid the expense of costly geared or automatic operating mechanisms. (One man using the Edward IMPACTOR Handwheel can produce sufficient torque to seat a 12 in. valve with 2000 psi under the disk.)

8 In higher pressure-temperature steam generating plants, pressure-seal bonnet designs are rapidly replacing the cumbersome, heavily-bolted bonnets. Here are several especially desirable features:

(a) pressure-seal bonnet joints stay tight regardless of temperature-pressure variations;

(b) fewer bolts, lighter covers and bonnets save time and labor, reduce maintenance costs;

(c) lower pressure drop in streamlined pressure-seal designs permit use of smaller piping and valves . . . saving space, weight and costs;

(d) and pressure-seal construction improves streamlining which reduces wear-inducing turbulence.

(Edward has built PRESSURE-SEAL valves for ten years and its continuing research has developed many new features that reduce maintenance and improve sealing qualities.)

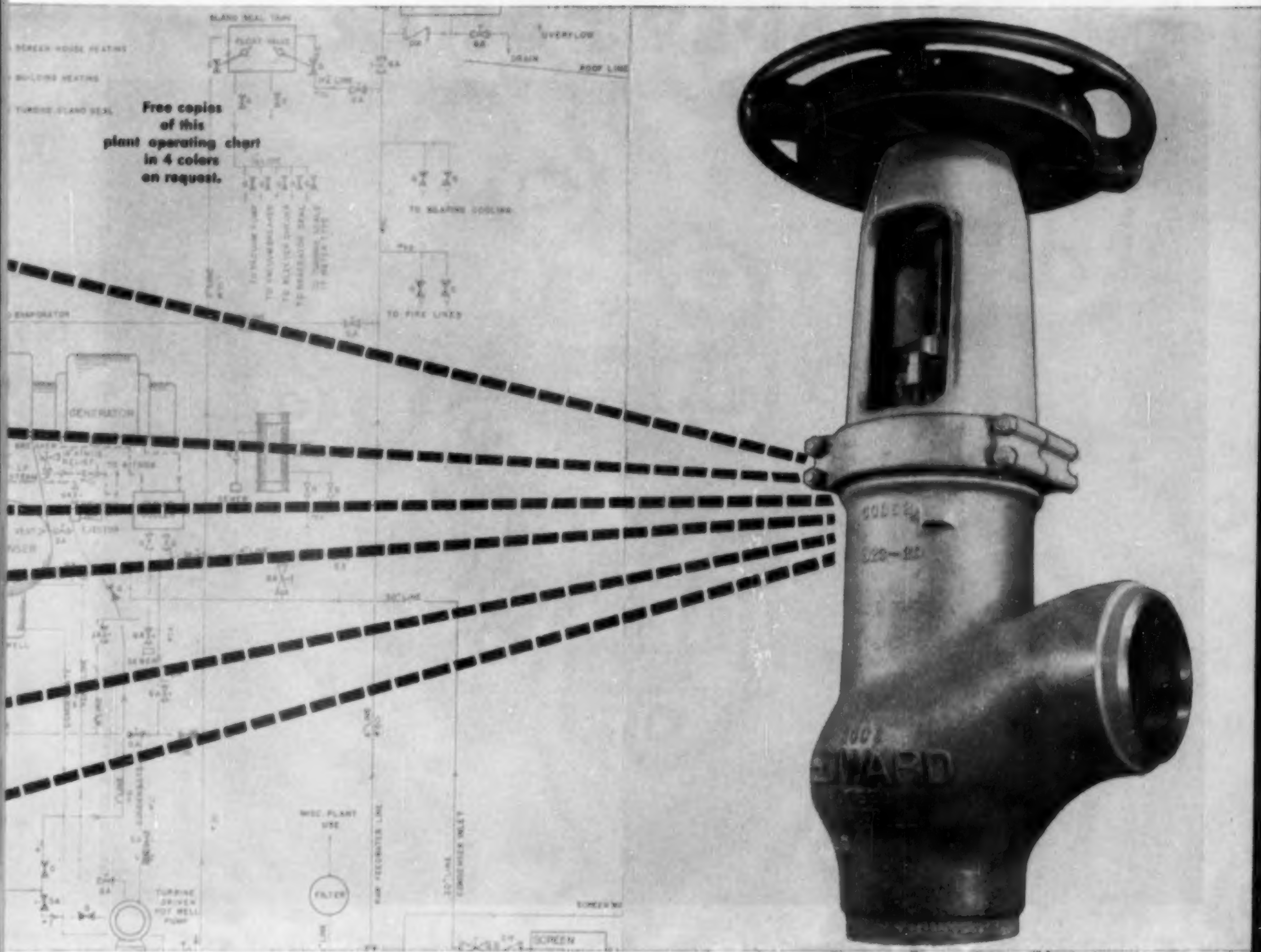
ASME BOILER CODE REQUIREMENTS . . . (excerpts) that control high-pressure stop valves.

P-301

Each steam-discharge outlet, except safety-valve, reheater inlet and outlet, or superheater inlet connections, shall be fitted with a stop valve located at an accessible point in the steam-delivery line and as near to the boiler nozzle as convenient and practicable. In the case of a single boiler and prime mover installation, the stop valve required by the Code may be omitted provided the prime mover throttle valve is equipped with an indicator to show whether the valve is open or closed and is suitable to

CAST STEEL

STOP VALVES*



withstand the required hydrostatic pressure test of the boiler.

A stop valve is not required at the inlet or outlet of a reheater or separately fired superheater.

P-302

All Stop valves and the fittings between them and the boiler shall be equal at least to the requirements of the American Standards given in Tables A-6, A-7, A-8, and A-11 for the maximum allowable working pressure and the temperature in service and material used.

The nearest steam stop valve or valves to the boiler drum or superheater inlet shall have a pressure rating at least equal to the minimum set pressure of any safety valve on the boiler drum at the corresponding saturated steam temperature.

The nearest stop valve or valves to the superheater outlet shall have a pressure rating at least equal to the minimum set pressure of any safety valve on the superheater and at the expected superheater steam temperature; or at least equal to 85 per cent of the lowest set pressure of any safety valve on the boiler drum at the expected steam temperature of the superheater outlet, whichever is greater.

P-303

When boilers are connected to a common steam main, the steam connection from each boiler having a manhole opening shall be fitted with two stop valves having an ample free-blow drain between them. The discharge of this drain shall be visible to the operator while manipulating the valve. The stop valves shall consist preferably of one automatic non-return valve (set next to the boiler) and a second valve of the outside-screw-and-yoke type; or, two valves of the outside-screw-and-yoke type shall be used.

P-304

When a stop valve is so located that water can accumulate, ample drains shall be provided. All drain lines, including pipe, fittings, and valves, shall comply with the requirements for steam piping or water piping according to the service.

P-317

(a) The feed pipe shall be provided with a check valve near the boiler and a valve or cock between the check valve and the boiler, and when two or more boilers are fed from a common source, there shall also be a globe or regulating valve on the branch to each boiler between the check valve and the source of supply. Wherever globe valves are used on feed piping, the inlet shall be under the disk of the valve.

(b) When the supply line to a boiler is divided so as to feed a drum in more than one place or to feed more than one drum it is recommended that each such branch line be equipped with a stop and a check valve even though the common source is equipped as required by (a).

(c) If a boiler is equipped with duplicate feed arrangements, each such arrangement shall be equipped as required by the rules.

(d) A combination stop-and-check valve in which there is only one seat and disk, and a valve stem is provided to close the valve when the stem is screwed down, shall be considered only as a stop valve, and a check valve shall be installed as otherwise provided.

(e) Where an economizer or other feedwater-heating device is connected directly to the boiler without intervening valves, the feed valves and check valves required shall be placed on the inlet of the economizer or feedwater-heating device.

**Only a few of the most important stop valves are highlighted in this illustration.*

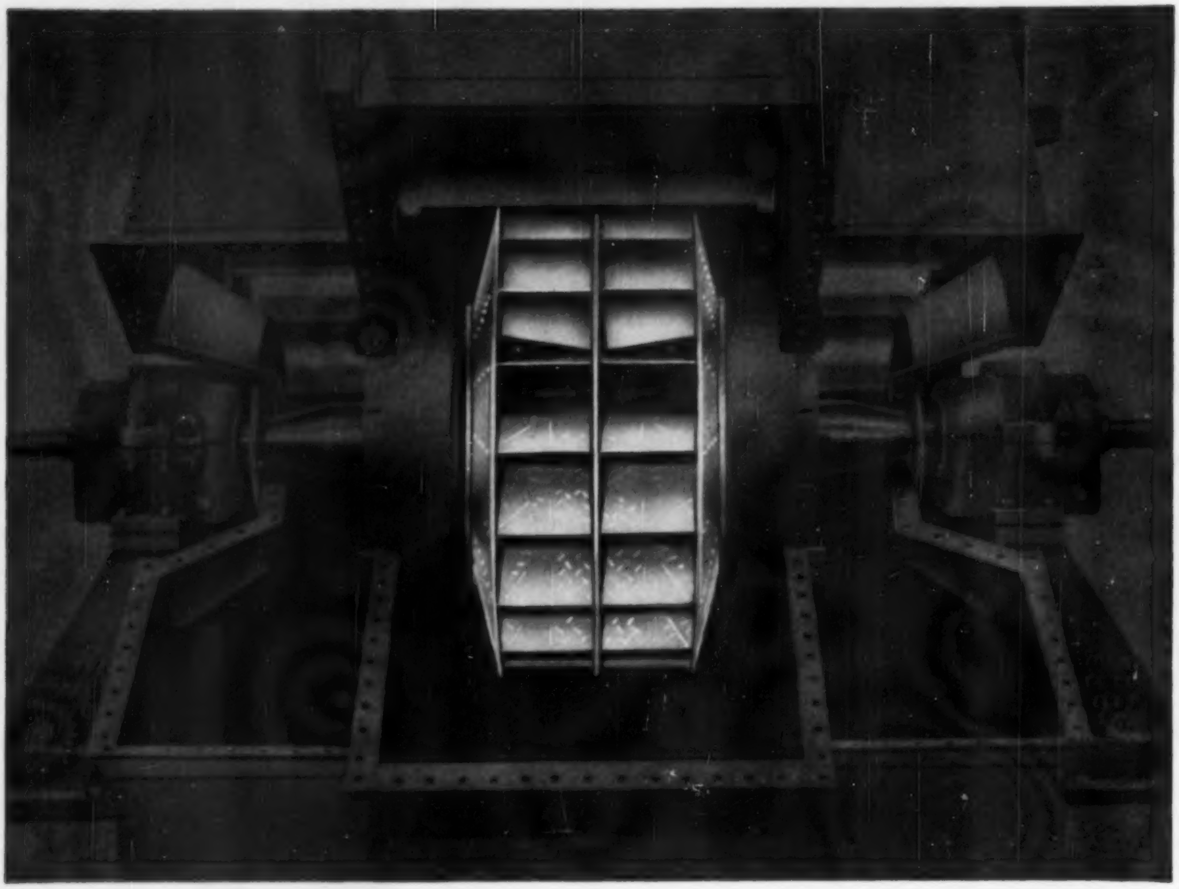
Edward Valves, Inc.

Subsidiary of ROCKWELL MANUFACTURING COMPANY

20 W. 144th St.
EAST CHICAGO, INDIANA

Another Product

How a FAN ROTOR Delivers CHEAPER POWER



. . . in "Buffalo" Induced Draft Fans

Inside the "Buffalo" Induced Draft Fan is a hurricane — a hurricane of hot, erosive fly-ash being drawn from the boiler fire-bed by a rotor like the one above. We don't have to tell you how quickly this could literally destroy an ordinary rotor — nor how expensive replacement would be. Yet the "Buffalo" rotor is built to "take-it" for a long period. Heavy gauge steel used throughout; backward curved blades for extra stiffness and efficiency — tapered side flanges cut from a solid plate—floor plate wearing strips with angular ridges to reduce erosion — heavy hub solidly bolted to the center plate. And all other parts of the fan — housing, shaft and bearings — are built to "go the distance" for you, which naturally means cheaper power. It's all part of the "Q" Factor* that's in every "Buffalo" Fan. You'll see full details in Buleltin 3750. Write for your free copy today!

** The "Q" Factor — The built-in Quality which provides trouble-free satisfaction and long life.*

"Buffalo"

BUFFALO FORGE COMPANY

170 MORTIMER ST. BUFFALO, N. Y.

Publishers of "Fan Engineering" Handbook

Canadian Blower & Forge Co., Ltd., Kitchener, Ont.
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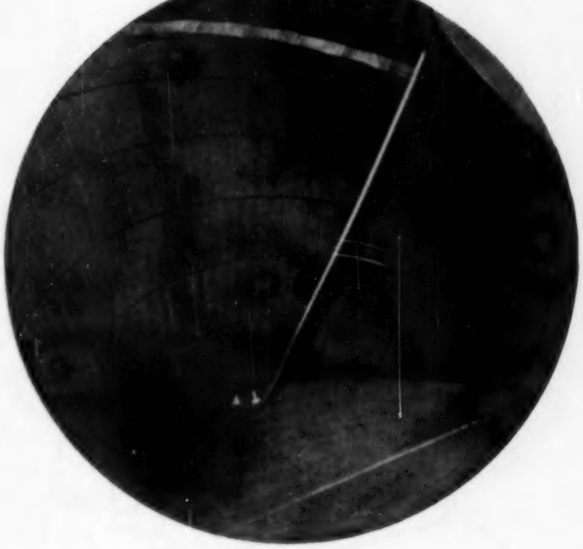
VENTILATING AIR CLEANING AIR TEMPERING INDUCED DRAFT EXHAUSTING FORCED DRAFT COOLING HEATING PRESSURE BLOWING



ARMOR PLATE
FOR CYCLONES . . .

The brick lining this cyclone dust collector are exposed to unimaginable abrasion and erosion. The blast is so severe it can eat through the hardest metals in no time. Yet linings made of CARBORUNDUM's silicon carbide last for years. This one has now been in use for *over three years.* (Note the single course that shows considerable wear. This is another material after just six months' service).

In each case HARDNESS is what pays

ARMOR PLATE
FOR BURNER RINGS

The direct blast from a pulverized coal burner contains a fiery abrasive. Millions of razor-sharp particles of coal are entrained in the flames. This destructive scouring is one reason these burner rings fail so fast. Unless, of course, they are made of our silicon carbide—which is not only super-hard, but *stays hard* even at extreme temperatures. It prevents erosion, and offers no foothold for slag build-up. In short, it *lasts* . . . and you get uninterrupted trouble-free steaming capacity.

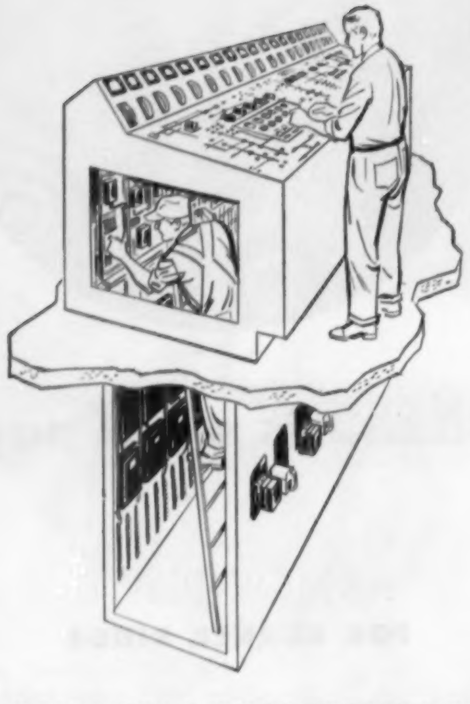
Complimentary Booklet

A 32-page summary of boiler trouble-spots where special properties of super refractories fit perfectly. For your copy address Dept. **E-95,** Refractories Division, The Carborundum Co., Perth Amboy, New Jersey

CARBORUNDUM

Registered Trade Mark

Jersey Central selects



MULTIPLE FUEL, CYCLONE FURNACE INSTRUMENTATION AND CONTROL BY HAYS, *for the new addition to Jersey Central Power and Light's Raritan River Plant, is mounted on this benchboard and auxiliary panels. The entire unit will be controlled from this centralized control station. The new steam generating unit has a maximum continuous steam output of 900,000 lbs/hr at 2050 psi and 1050 degs F with 1000 degs F reheat. It is of the pressurized furnace type with superheat and reheat steam.*

BEACON PROCESSED POCAHONTAS

prepared in one of the largest, best equipped and most modern cleaning plants in the entire nation

Ask any group of coal users the fuel name they've known best and longest—and most will say "Pocahontas." It's been a famous name for almost a century, because coal from this field has been an acknowledged leader in cleanliness, good-burning properties, and all-round quality.

Beacon Processed Pocahontas Stoker Coal makes it possible for you to offer your customers something even better than this "best." One of the newest, largest, and best-equipped cleaning plants in the entire nation is at work at the Keystone mine, adding an *extra* touch of ultimate quality to the natural advantages of the fuel. This coal lets you say to your customers, "I'm giving you the finest thing in stoker coal it is possible to buy."

EASTERN GAS AND FUEL ASSOCIATES

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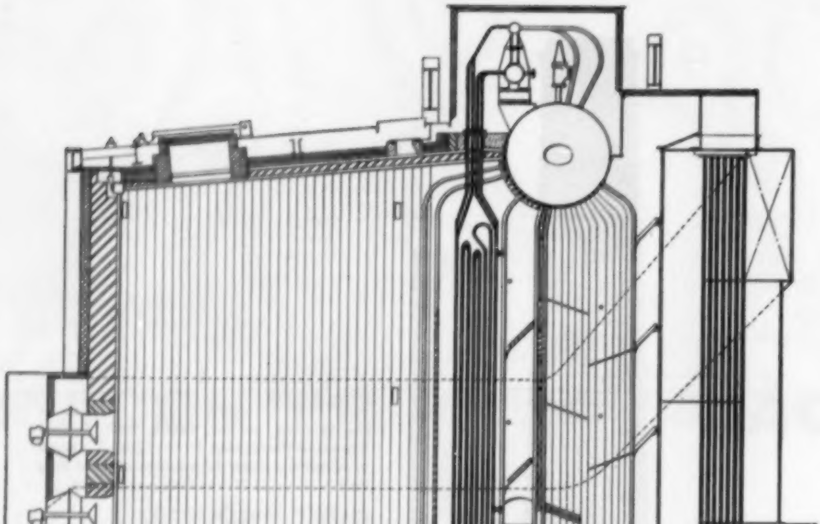
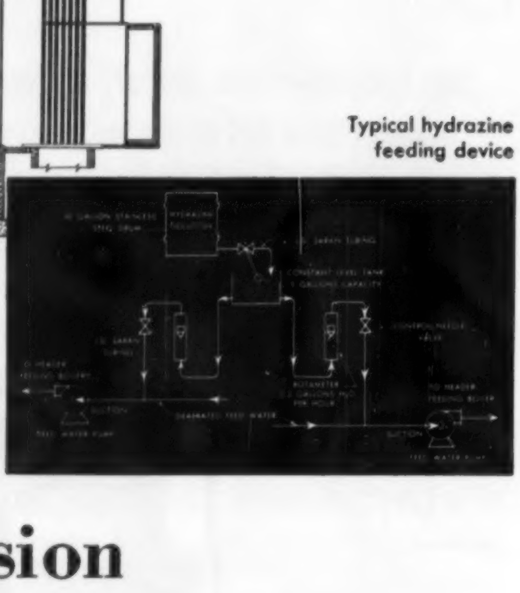
PHILADELPHIA • SYRACUSE

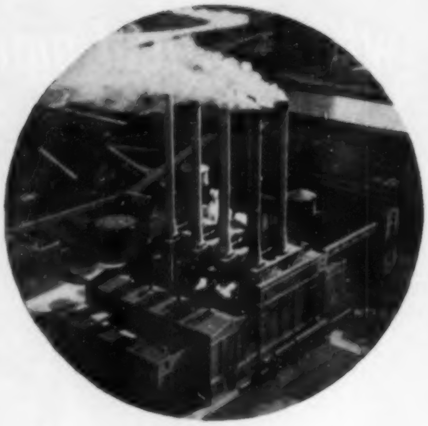
For New England: New England Coal & Coke Co.
For Export: Castner, Curran & Bullitt Inc.



Typical hydrazine feeding device



Latest additions to Ford Motor Company's power plant are two drum bent tube twin boilers. Each has 3,948 tubes. Evaporation, 500,000 lbs. steam per hour. Temperature at Superheater outlet 650°F. Pressure at Superheater outlet 250 p.s.i.g.



Ford uses ELECTRUNITE boiler tubes in

This latest boiler installation is part of Ford's continuing modernization program. At the Rouge, which has the largest industrial power plant in the world, Combustion Engineering Inc., is furnishing specially designed boilers.

The ELECTRUNITE Boiler Tubes used are made from high grade steel, made in Republic's own mills. Quality is controlled from ore to finished product through a series of rigid tests and inspections.

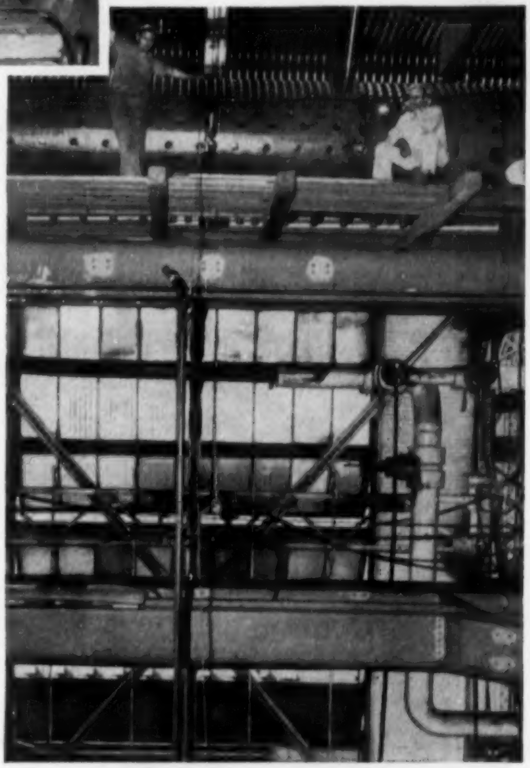
The results: Tubes with uniform wall thickness which give uniform heat transfer all around the tube and from end to end. Uniform ductility for smooth bending and uniform roller-expanding.

Every ELECTRUNITE Boiler Tube has identical metallurgical and physical properties. Because wall thickness is uniform, there are no longitudinal thin spots. This results in uniform heat transfer.

Surfaces of ELECTRUNITE Boiler Tubes are scale-free because they are normalized in a controlled atmosphere. This saves grinding tube ends which destroys uniformity. Tubes slide into drum holes easily, expand uniformly.

•

Because of ELECTRUNITE'S uniform ductility, accurate bends are easily made, and spring-back can be calculated before bending operation.



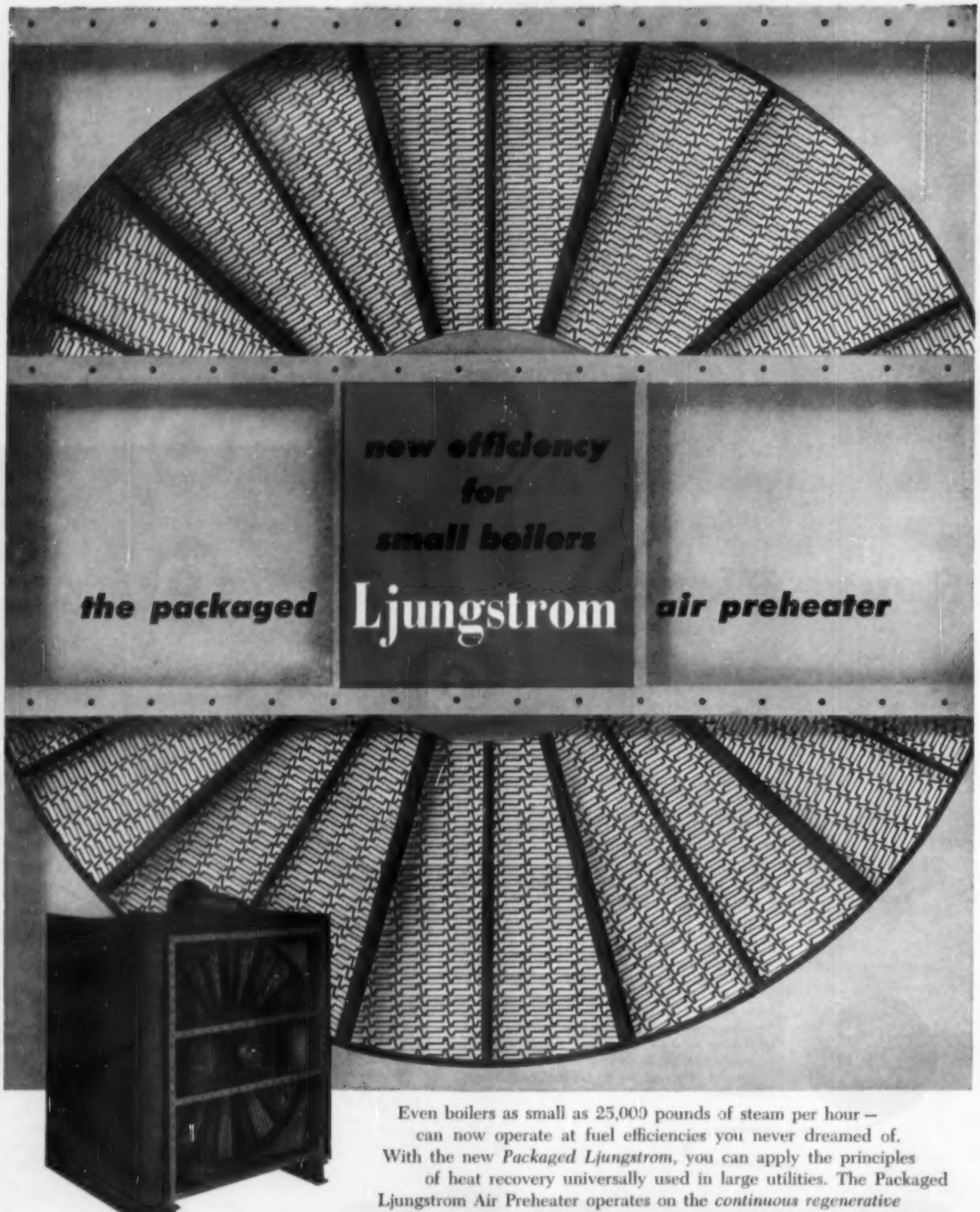
Rouge Plant

From the standpoint of economics, it pays to consider ELECTRUNITE Boiler, Condenser and Heat Exchanger Tubes. Write for the booklet that gives you complete data and specifications.

REPUBLIC STEEL CORPORATION
Steel and Tubes Division
209 East 131st Street, Cleveland 8, Ohio
GENERAL OFFICES • CLEVELAND 1, OHIO
Export Department: Chrysler Building, New York, 17, N. Y.

"INTESTINAL FORTITUDE"—16 mm., sound, black and white, 17 minutes. The story of ELECTRUNITE pressure tubes. A short introduction reviews the progress of the iron ore from mines to blast furnace. Then the various steps necessary to make the flat-rolled coils of steel from which the tubing is made. Finally, how ELECTRUNITE tubing is made. To arrange for showing, write to Steel and Tubes Division.

Republic
REPUBLIC STEEL
ELECTRUNITE
BOILER, CONDENSER AND HEAT EXCHANGER TUBES



Even boilers as small as 25,000 pounds of steam per hour — can now operate at fuel efficiencies you never dreamed of. With the new *Packaged Ljungstrom,* you can apply the principles of heat recovery universally used in large utilities. The Packaged Ljungstrom Air Preheater operates on the *continuous regenerative counterflow* principle. Waste heat in products of combustion is absorbed on specially designed surfaces in the slowly rotating rotor. As the surfaces enter the stream of incoming combustion air, they transfer their heat to this air. The entire unit is self-contained as you receive it.

For more detailed information — get in touch today with The Air Preheater Corporation.

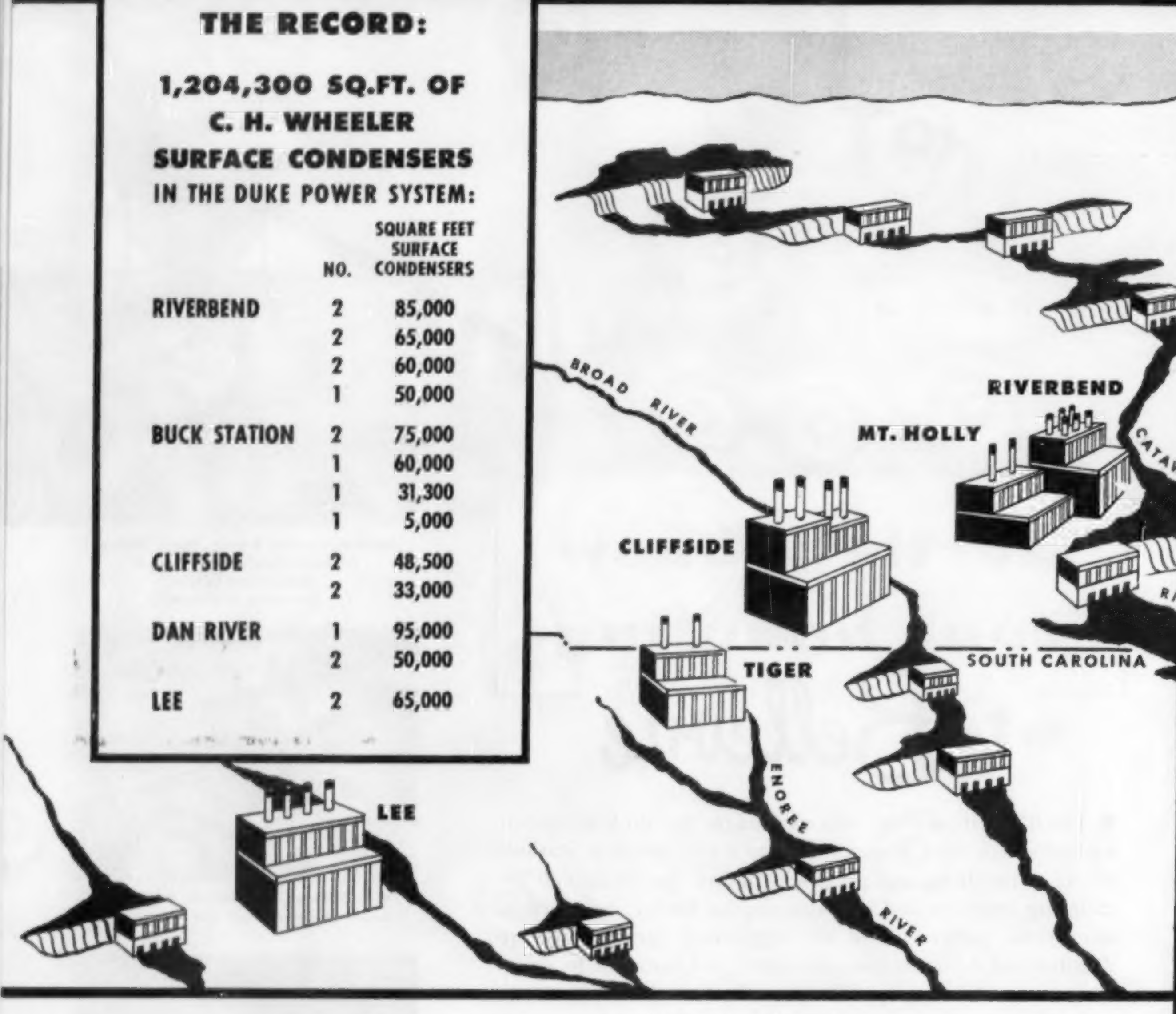
The Air Preheater Corporation 60 East 42nd Street, New York 17, N. Y.

DUKE POWER *picks*

THE RECORD:

1,204,300 SQ.FT. OF C. H. WHEELER SURFACE CONDENSERS IN THE DUKE POWER SYSTEM:

	NO.	SQUARE FEET SURFACE CONDENSERS
RIVERBEND	2	85,000
	2	65,000
	2	60,000
	1	50,000
BUCK STATION	2	75,000
	1	60,000
	1	31,300
	1	5,000
CLIFFSIDE	2	48,500
	2	33,000
DAN RIVER	1	95,000
	2	50,000
LEE	2	65,000



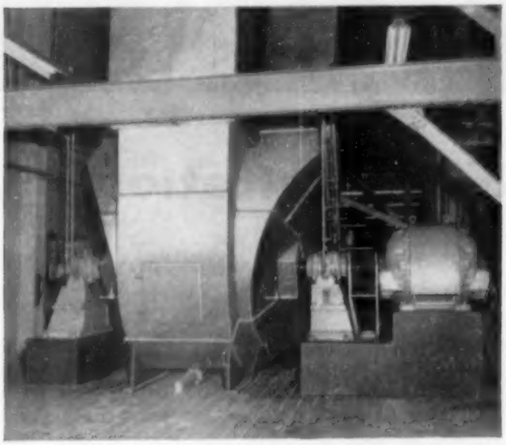
C. H. Wheeler Steam Condensers, Air Ejectors, Circulating and Condensate Pumps are tried and trusted equipment in every new steam power generating station that Duke Power has built. Photos show some of the latest installations in the new Buck Station where five C. H. Wheeler Surface Condensers are installed, ranging in size from a 5000 sq.ft. house turbine unit to a 75,000 sq.ft. unit. All other steam stations on the Duke system are completely equipped by C. H. Wheeler. This equipment is designed to strike a sound balance between first cost, operating efficiency and maintenance costs.

There's progressiveness in C. H. Wheeler engineering that matches the expansion plans of a great utility like Duke Power. A new 95,000 sq.ft. Surface Condenser Unit and auxiliaries is now being manufactured for Dan River Station.

The art of condensing steam and producing vacuum for the prime movers of industry has the seasoning of 50 years of development at C. H. Wheeler. You can find no richer experience . . . no greater vision for the future of steam power generation . . . than at C. H. Wheeler of Philadelphia. . . . ***HOW MAY WE HELP YOU?***

Florida Power Corporation keeps pace with rising needs for electricity

In 1897, the first plant of what is now the Florida Power Corporation went into operation with a wood-burning boiler and a 50 kw generator. Today, Florida Power and its subsidiary, Georgia Power and Light Company, serve 31 counties in Florida and 21 counties in Georgia. Total capacity is now 408,300 kw!



Here's another American Blower Sirocco Induced Draft Fan at the Higgins Plant. It is rated at 145,400 cfm, 695 rpm and 10.9" sp. Throughout the power plant industry, American Blower's experience and know-how are helping plant operators solve their power plant problems.

Naturally, this continued expansion has been based on the growing needs of the area for low-cost electricity for homes, business and industry. Future needs are anticipated and planned for . . . years ahead of time.

Like other investor-owned utilities, Florida Power keeps output high and costs low by selecting dependable, efficient equipment — including American Blower Forced and Induced Draft Fans.

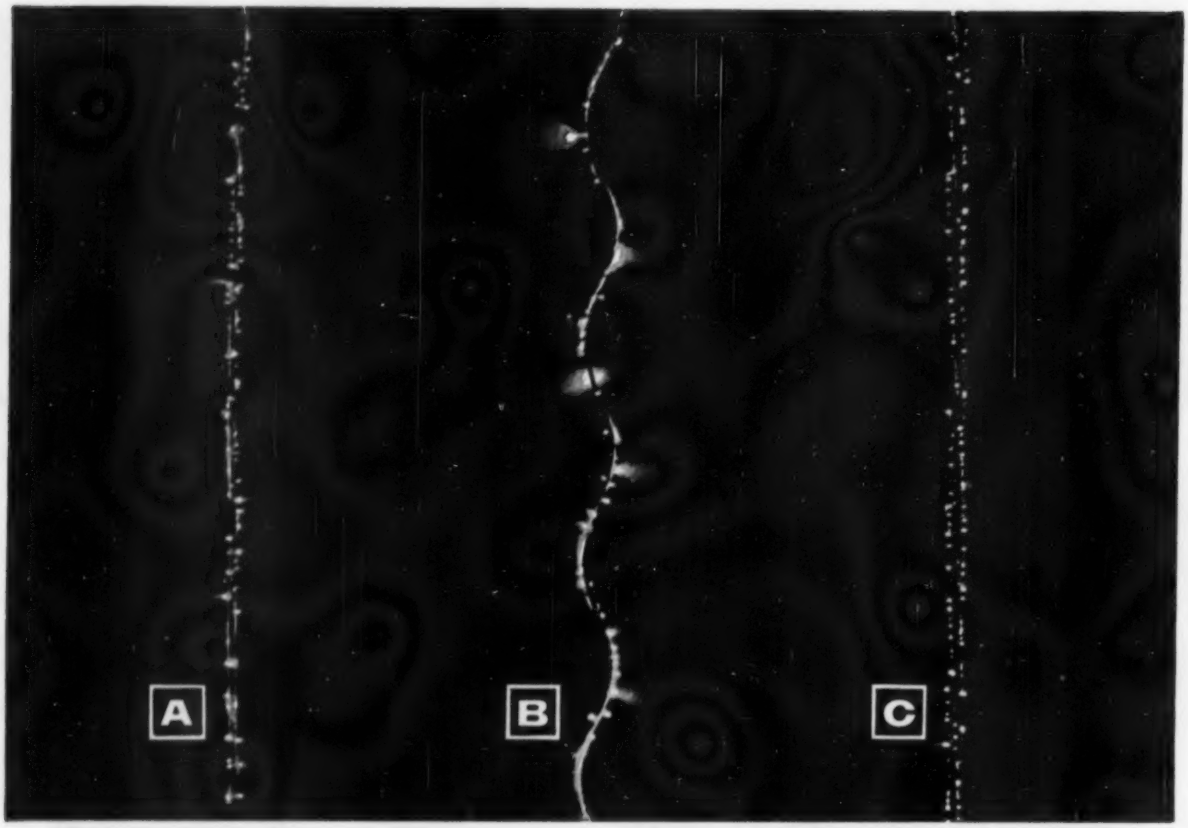
Power plant operators everywhere are specifying American Blower Mechanical Draft Fans, Dust Collecting Equipment, Fly Ash Precipitators and Gyrol Fluid Drive for boiler feed pump and fan control. They know they can depend on American Blower Equipment and American Blower technical assistance.

If you have an air handling problem, or are planning to expand or modernize, find out how American Blower can help you. Contact your nearest American Blower Branch Office, or write us direct.

AMERICAN BLOWER CORPORATION, DETROIT 32, MICHIGAN
CANADIAN SIROCCO COMPANY, LTD., WINDSOR, ONTARIO
Division of American Radiator & Standard Sanitary Corporation

AMERICAN BLOWER

AMERICAN BLOWER • CHURCH SEATS & WALL TILE • DETROIT CONTROLS • KEWANEE BOILERS • ROSS EXCHANGERS • SUNBEAM AIR CONDITIONERS



The [A][B][C] of Electric Precipitation

The efficiency of *any* electric precipitator depends on the quality of the corona emission from the electrode, for it is this emission that 'charges' the dust.

Pictured above are the three most frequently used electrodes for doing this job. You can see the quality of the corona for yourself. We'll be glad to give you an actual demonstration.

Other precipitators use electrodes A and C which give off only fair emission. Use of fine wire (to increase emission) leads to structural weakness. Use of heavy wire (to give strength) means poor emission.

The exclusive Buell Spiralectrode (B) combines strength with peak emission.

The outstanding on-the-job performance of the new Buell Spiralectrode is typical of the advances made by Buell Engineers. Continuous-cycle rapping, for example, proved in service for 20 years has *never* caused "puffing".

Buell has consistently led the way to greater efficiency, through a long series of technical discoveries and advances, in all types of dust collection.

Get all the facts. Send for our informative brochure–The Collection and Recovery of Industrial Dusts. It explains all three Buell Systems of industrial dust collection. Send for your copy today. Write Dept.70 I, Buell Engineering Company, 70 Pine Street, New York 5, New York.

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20 Years of Engineered Efficiency in

DUST COLLECTION SYSTEMS

COMBUSTION

Editorials

New Horizons for Steam Power

Ever onward and upward in efficiency, size and steam conditions—that is what has characterized the central station industry since the days of Edison's pioneering Pearl Street Station. Another bold step forward has just been announced by the Philadelphia Electric Company, technical details of which are revealed on page 73. The combination of the world's largest turbine-generator and a super-critical pressure boiler designed for record high steam temperature and pressure will result in power generation at the highest efficiency and lowest heat rate ever achieved.

The next decade in power generation promises to be an exciting one. Unquestionably nuclear reactors will have an important role to play, and the five-year development plan of the Atomic Energy Commission will be followed with keen interest. But it is increasingly evident that progress will not be confined to nuclear-fueled stations. In May 1953 the American Gas and Electric Company announced plans for the first commercial station employing steam at a pressure above the critical and incorporating two stages of reheat. The net result of this and similar projects will be appreciable fuel savings in conventional fuel-fired plants.

Advancing technology brings into being forces that are both interacting and competitive. The prospect of widespread application of nuclear energy is a challenge to all power-plant designers. At the same time it provides an opportunity for the introduction of new engineering techniques that will find use in many well established technical fields. It is the ultimate user of electric power who stands to benefit most from this alliance of competition and technical interchange.

Great credit belongs to the Philadelphia Electric Company for the willingness to make the investment that brings this new power horizon closer to reality. The accolade should be all the stronger because this is not a halting step forward but a bold one in which an attractive economic return is linked to technological highs in unit size, steam conditions and power-generation efficiency.

The Battle for Jurisdiction Over Air Pollution Control

Just last month we commented on the exploratory conference on air pollution problems called by the Joint Legislative Committee on Natural Resources of the State of New York. At that conference various state departments presented their positions on air pollution control and in some instances outlined how they could function in achieving the desired controls. Certain municipal officials and county health officers advanced their contentions as to where the control authority should rest. Our attention has been called to still another hat in this ring.

The United States Public Health Service in a testimony submitted to the Senate Appropriations Committee, April 16, 1954, by Oveta Culp Hobby, secretary, Health, Education and Welfare, inferred that the Nation faces, in the years ahead, an increase in pollution directly proportional to the projected increase in manufacturing production. Dr. Mark D. Hollis, also of the Public Health Service, further stated, according to the *New York Times*, July 5, 1954, that very little research is being done; that a minimum of information is available in the field of air pollution abatement; and that present scientific knowledge on air pollution is in as elementary a state as that which existed on water pollution in 1920. The purpose behind both statements was to justify appropriations for Public Health Service participation in air pollution control studies.

The Manufacturing Chemists Assn., for one, questioned the accuracy of the testimony before the Senate Committee as well as the quoted statements of Dr. Hollis. And rightly so, we believe. The power field has long been keenly interested in air pollution control. The oil industry has contributed significantly to overall knowledge in this area particularly through its sponsored studies at the Stanford Research Institute. All in all the Public Health Service's approach to the problem does not augur any constructive additions to the general knowledge of air pollution should they obtain their desired appropriation.

This need for constructive action is fundamental if air pollution control is ever to become workable. There are many individual companies that have backed up their desire to clean up the air by investing, in the aggregate, literally millions of dollars in the latest air pollution control equipment. What's more certain industries have gone beyond their own doors to aid in cleaning up communities. Outstanding among these are the Coal Producers Committee for Smoke Abatement with an imposing list of cities wherein they have earned the gratitude of citizens, plant owners and city administrators. Now we understand the Manufacturing Chemists Association is planning pollution abatement "workshops" in chemical plant communities to help solve pollution problems at their source. All are evidences, to our way of thinking, of a constructive approach. When governmental officials and legislators employ the same approach air pollution control will experience decided progress.

Fig. 1.—Unusual topography characterizes the Oak Creek site. The central service building, foreground, will ultimately be flanked with four units on both sides. See Fig. 9 for plan view. Note coal dock, ship channel, right

*Developmental Designs and Operating Experiences of the Oak Creek Plant**

Unconventional designs yet ones that afford the best promise for the future were deliberately selected for this new station. Results indicate high reliability and availability at attractive operating costs and good overall efficiency.

By M. K. DREWRY

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THE strongly antagonistic nature of reliability, thermal economy and initial cost of power plants encourages continuance of industry-wide pooling of engineering knowledge and experiences. For example, striving for higher thermal efficiency has not been without strong influences to impair reliability and to increase initial costs. Despite these opposing influences, electricity is unique in that its cost has increased but little with inflation. The free interchange of engineering knowledge and experience seems creditable to an appreciable extent. Every new power plant and its significant operating experiences can well be described in literature of the engineering societies.

Consistent evolution of power generation technique requires that present designs be adaptable to future ones. To do otherwise requires progress from a series of revolutionary advances, some of which are likely to prove uneconomic or unsuccessful. The controlled-circulation boiler and the cross-compound turbine, for instance, were selected, in part, for Oak Creek Power Plant because they were thought to represent required designs for future higher pressures, temperatures and capacities.

Turbine Basic Design

A low cross-over pressure of 10 psig between the 3600-rpm high-pressure section and the low-pressure section, two stages of 1000 F, and the 1800-rpm section designed for economic leaving losses at 0.5 in. absolute exhaust pressure, characterize this new cross-compound turbine selected for Oak Creek. Its unusually low cross-over pressure causes 2.2 times as much generation in the high-speed section as in the low-speed one. The respective generator capacities at 120,000 kw total are 82,700 kw for the high-speed and 37,300 kw for the low-speed one.

Besides the economic virtue of maximum generation with the smaller (3600-rpm) parts, Fig. 2, are savings in first cost and operating cost produced by minimizing the number of dual-flow low-pressure stages without requiring an extra cylinder. Blade heights are favorable, and

* Presented before the Fall Meeting of the American Society of Mechanical Engineers, Milwaukee, Wisconsin, September 8–10, 1954.

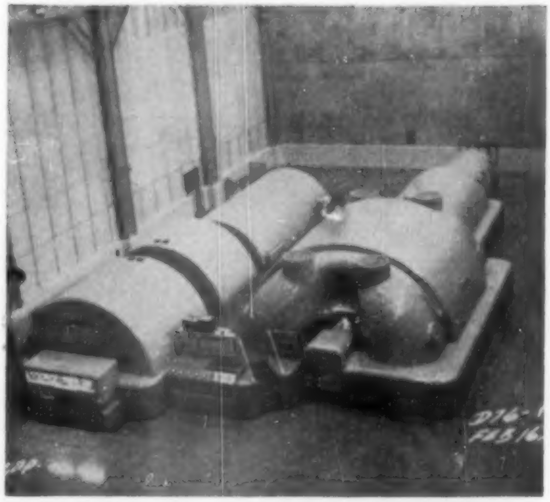


Fig. 2.—Compact, cross-compound-design turbine generates 2.2 times as much energy in high pressure, 3600 rpm section (left) as in low pressure, 1800 rpm section, (right)

The direct coupling possible with an internal strut results in cross-under vacuum and pressure forces being applied equally to both sides of the LP casings and no variable pressure build-up on IP casing.

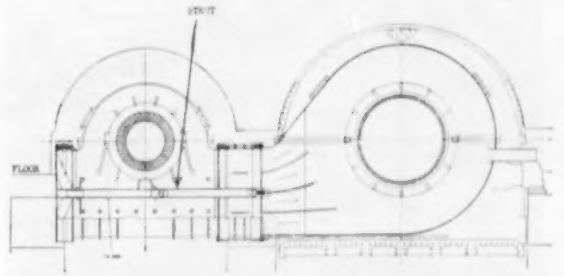


Fig. 3.—Cross-sectional view of turbine, Fig. 2, pictures how internal strut and expansion joints permitted cross-under duct to alleviate pressure forces on duct ends

unproductive flow resistances are minimized. The exhaust blade area is 213 sq ft, equivalent to six rows of 23-in., 3600-rpm blades.

Low cross-over pressure obviously requires a large flow area. Initial designs employed an overhead cross-over pipe and 33 ft between spindle centers. Because accessibility was poor, alternatives were studied. Some means of coping with the variable-with-load vacuum and pressure forces acting laterally on the turbine cylinders had to be found if a direct connection with an expansion joint was to be employed. Distortions caused by these variable forces would be destructive of efficiency.

An internal strut in the "cross-under" duct, Fig. 3, gives the equivalent of cover plates on both sides of the low-speed cylinder and of no closures on the high-speed cylinder openings. Thus, the variable pressures balance perfectly, and low blade and packing clearances can be employed, and retained.

By means of this unusual design shaft centers were brought 11 ft nearer, reducing their 33-ft separation to 22 ft. Flow losses were minimized and the resulting cross-under joints, unlike the conventional cross-over design, need never be broken and can therefore be welded. Accessibility was improved. The necessary turbine-room height and width limits were lessened. As a result Oak Creek's cross-compound design employs only 10 ft, $8^1/_2$ in. more turbine-room width than does Port Washington which has a tandem-compound turbine. (71 ft, $2^1/_2$ in., and 60 ft, 6 in. respectively.) Thus, a compact cross-compound design, of favorable initial and operating costs and with components of proved reliability, was evolved through close cooperation with the manufacturer's engineers. Adaptability to 500 mw, a valued merit, has been stated by the manufacturer.

Controlled-Circulation Boiler

Safety and continuity of service upon tube rupture were among the major reasons for selection of a pumped or controlled circulation boiler. Experience with several large ruptures of 3-in. O.D., 1300-psi, boiler tubes showed that induced-draft fan capacity was normally unable to remove the large quantity of steam evolved, resulting in opening of furnace and setting doors and dirtying and darkening the entire boiler room. Immediate loss of load always resulted, and many rolled tube joints were caused to leak on occasions. Since spinning standby for the largest unit is not always carried this loss of load can be a problem.

This is not a disadvantage, however, with a controlled circulation boiler. The relatively small ($^5/_8$-in. O.D.) and orificed tubes of this boiler design can rupture without requiring outage before other equipment can be activated. Hence their safety and continuity-of-service merits are considerable.

But there were still other reasons for selecting controlled circulation. The steady advance of steam pressure throughout the five Port Washington units from 1230 to 1480 psi and the continued pressure advance of the Oak Creek units (subsequently 200 psi for each of the No. 2 and 3 units) suggested preparing for the time that natural boiler circulation became precluded.

Relatively rapid cooling for maintenance was another factor urging controlled circulation. With natural circulation, hot water stays in the upper drums and cannot ordinarily be cooled at a reasonably rapid rate. With forced circulation, the banks of convection tubes serve as efficient coolers. Oak Creek boiler cooling rate is almost three times that of Port Washington (100 F per hour versus 35 F), thus saving 10 hours when cooling from 615 F to 80 F. Fixed charges for 10 hours total \$2000, and coal savings during the five weekdays are often about \$1200 for 10 hours, making more rapid cooling worth \$3200 per maintenance outage.

Controlled circulation has several other significant values and minor demerits as well. The pumps require one-quarter per cent of full load output and are not without maintenance. However, they have not been responsible for impaired outputs. Development is reasonably expected to reduce needed attention.

Boiler-Furnace Basic Design

A means of closely sustaining 1000 F reheat through-

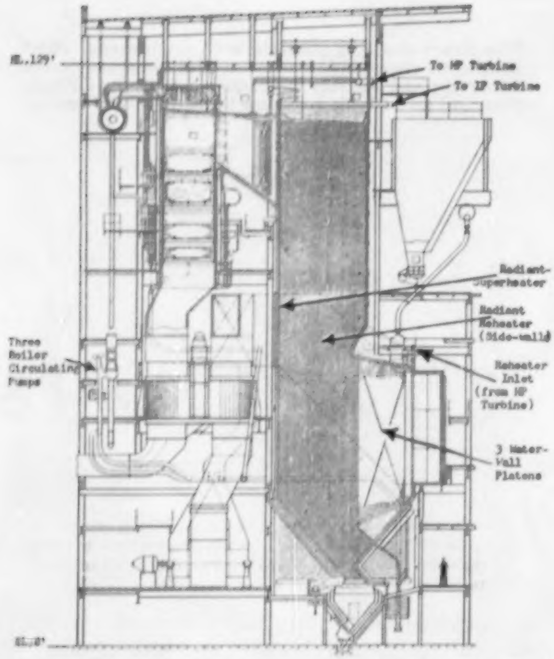


Fig. 4.—Platen walls, located in the region of highest heat transfer, aid in attaining a self-cleaning furnace as well as assisting in the control of reheat steam temperature

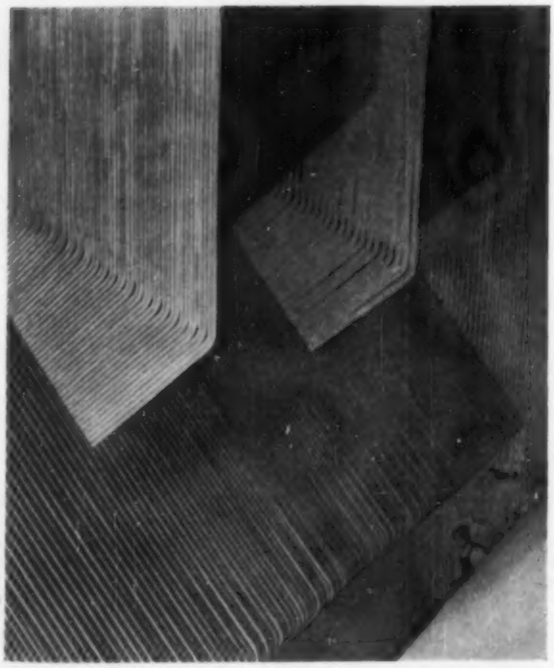


Fig. 5.—Clean furnace after two months service reflects effect of the platen walls (two of the three show here, radiant reheater wall background, superheater, right foreground)

out the load range, an objective not fully reached at Port Washington,[1] plus more nearly perfect freedom from furnace manual cleaning than at Port Washington, were sought in the basic design of the boiler furnace.

Study suggested that if Port Washington's radiant superheater and radiant reheater positions were exchanged, differential firing across the furnace width could cope with the reheater-inlet temperature drop with load that modern multi-valved turbines cause. Port Washington experience showed that two "fires," one near each side-wall, were necessary at low loads to maintain superheat temperature, but little value resulted in augmented rear-wall reheater heat adsorption.

The dual function of assisting with low-load superheat and reheat steam temperature regulation, and of assisting importantly with furnace cleanliness, is afforded by three "platen" walls interposed under the arch between burners, Fig. 4. They form four "cells" across the furnace front. The two middle cells are bounded on their three vertical sides with water tubes. The two end cells have as their outer walls the side-wall radiant reheaters. Differential firing of the center and end cells affords a means of varying relative evaporating and reheating, and thus regulating reheat steam temperature. The platen walls act as shields, shading water tubes or reheater tubes from the flames, as desired.

Because these platen walls receive heat on both sides at about the highest rates experienced in the furnace, they effectively limit furnace temperatures and thus minimize ash deposits that require manual removal.

Though the local flame temperatures are high, deposits on the platens or nearby surfaces have proved to be negligible. With the flame travel downward, and roughly parallel to the vertical tubes, air and flue-gas currents acting in the same direction as gravity assist it in keeping these surfaces clean.

The location of the platens in this maximum heat transfer zone makes them most effective in regulating reheat temperatures and maintaining furnace cleanliness. If the platens were located near the furnace outlet, for instance, the entire furnace would be hotter, thus permitting ash deposits that would require manual removal. Experience suggests that the rear sloping bottom and rear-wall would accumulate most ash, for walls directly under the burners are consistently cleaner, notwithstanding the high temperature.

Lower furnace heat-transfer rates have other important values besides minimizing expensive manual ash removal. In general, boiler-unit availability and reliability appear highest with lowest furnace temperatures. The relatively "cool" furnaces of Port Washington boiler units over the years have contributed to experiencing closely 43 per cent of the scheduled maintenance outage time and 15 per cent of the forced outage time of average power-industry boiler units. Thus, with less than one-half the opportunity for preventive maintenance, these lower furnace temperature units have been forced from service only one-sixth as much. No characteristic of apparatus exceeds availability and reliability in value.

Lower furnace and boiler-inlet temperatures permit significantly lower pressure drops in superheaters and reheaters for the same metal temperature, thus aiding station thermal efficiency. Because heat transfer rate varies with the 0.8 power of the mass-flow rate, and since pressure drop varies with the square of the latter, pressure drop decreases rapidly with heat input rate. For instance, halving of heat input rate, for the same metal temperature, sends pressure drop down to only one-third.

[1] Reheat Experiences at Port Washington, ASME paper 51-A-45.

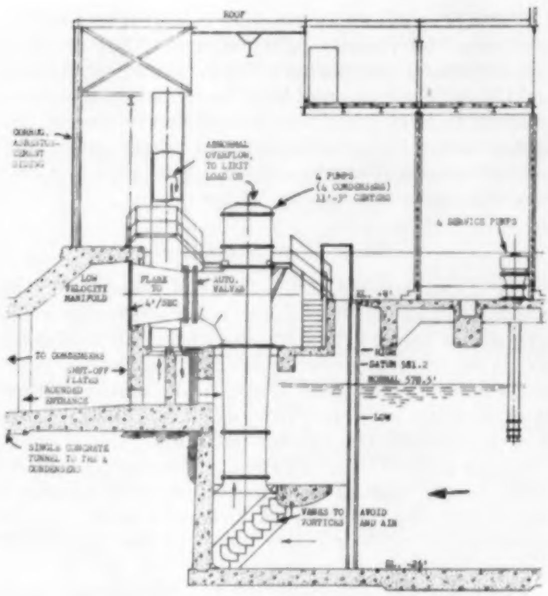


Fig. 6—Condensing water quantities approach those of hydro plants. The use of similar design techniques to reduce flow resistance captures substantial gains

Fig. 7—Vaned elbows remove and reject each condenser's circulating water at the same velocity and direction as the main flow, thereby reducing pumping costs

For the industry's steadily increasing steam temperatures, lower heat input rates are valuable in limiting metal temperatures and wasteful pressure drops.

Condensing Water System

To cope with the hazard of a 10-minute 6-ft to 7-ft rise of Lake Michigan water level (experienced only 10 miles away at Racine in 1944 during a year of high levels and in the absence of winds) and still be at the same height as the Lakeside and Port Washington first floor levels required raising basement level 6 ft at Oak Creek. This action required 6 ft less condenser height. Width considerations also suggested a central pump room.

By manifolding the discharge of four condenser circulating pumps serving four condensers, rather than using two pumps per condenser, and by using higher speed pumps and reduced flow resistances, pump costs per plant kw, compared with Port Washington's, were halved.

Use of hydraulic principles employed in hydroelectric plants permitted a condensing water flow circuit of low resistance. "Stepped" intake and discharge tunnels, with water removal and injection from the tunnels' tops by means of vaned elbows, Fig. 7, to conserve the tunnel velocity; use of flares where velocities are reduced; and minimizing of tunnel openings—all combined to reduce flow resistances (other than condenser-tube friction) to one-third of previous practice. Fig. 6 shows in part the pump room cross-section.

Vertical pumps avoid the need of priming, thus improving reliability, especially in emergencies, and facilitating remote control. Excessive motor overloads are reliably avoided by employment of stand-pipe overflows, which proved valuable when the system was seriously troubled with heavy industrial waste.

Condenser inlets carry valves for control-room throttling of flow to as little as one-fifth, as required to cope with ice, fish or debris. This throttling has proved of extremely high value at Lakeside, Port Washington and Oak Creek for avoiding complete plant shutdowns.

Piping Welds

Backing-ring omission on piping welds removes the hazard of ring portion's loosening by vibration and injuring turbine blading. Possibly still more important, it reduces stress concentration points, and therefore eases the normal cracking tendency of the $2^1/_2$ per cent chrome, 1 per cent molybdenum, T22 alloy.

Developmental work with heliarc welding proved that by expert welding, satisfactory root beads could be made without use of internal gas pressure. Experience proved that cost and erection time were substantially reduced.

As an unexpected virtue, ultrasonic confirmation of sound welds was found wholly practical. For the few cases where internal diameters are not accurately coincident, rechecking after several months or years of operation is expected to confirm all of the joints of perfect safety. Ability to use the ultrasonic testing method, with its extremely sensitive, reliable indications, is a major virtue of backing-ring omission.

Turbine Oil-Fire Isolation

Essentially total isolation of each boiler-turbine unit from others is obtained in spite of keeping the space above the turbine operating floor fully open for unimpaired crane service.

All oil pipes are located below the relatively tight turbine casings, which are sealed to the turbine floor, which is also tight. Stairs to lower elevations are enclosed and have doors at the first landing, to complete sealing of the turbine-room floor.

Since the units are being installed individually, at 1- to 2-year frequency, each structure requires a temporary

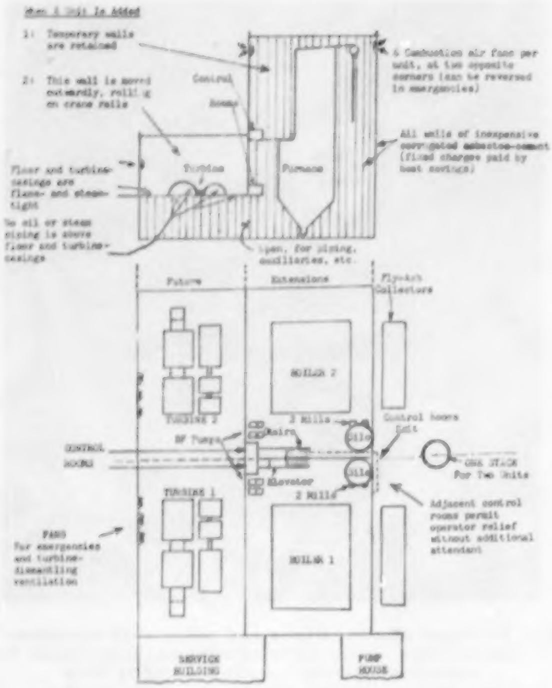


Fig. 8—Boiler-turbine isolated units, centralized about a common line, permit operator relief without extra attendants; also afford complete isolation in event of fire

end wall. The wall above the turbine-room operating floor is readily rolled to its new location while supported on the crane rails. The wall beneath it, and the entire relatively inexpensive boiler-room wall, are left in place. The boiler and condenser spaces of each unit are common, for no wall exists between them below the turbine operating floor. Thus, an oil-fire, a coal or hydrogen explosion, or a large steam leak impairs but the one unit. Fig. 8, top, illustrates this isolation plan.

Minor leakage of smoke or steam through the turbine casing can be routed outside by control-room opening of windows opposite the turbine in trouble, while large ventilating fans opposite the remaining turbines help insure their continued service. These fans are also used for cooling workmen when dismantling a turbine in summer. Rotatable louvers can direct outside air to areas desired. Turbine parts are often warm, and favorable ventilation can reduce outage time substantially on occasions. Shortening outages is of high value.

Isolation walls between each unit assist firefighting when emergency conditions occur. Turbine oil-tank and piping sprays, installed permanently in strategic positions, are activated from adjoining spaces. Doors in these walls afford portals through which firefighting can be continued as needed, under cover of the isolating walls. Boiler-room ventilating fans, mentioned later, can be reversed from the control room to minimize smoke or steam density.

Operators feel encouraged to stay at the controls longer in extreme emergencies by provision of an enclosed passageway from the control rooms, ventilated with outside air. Their stopping of apparatus with minimum possible damage seems reasonably expected.

These precautions for extreme emergencies have not substituted for primary safety efforts. They are desirable for wholly unexpected events. Control-room walls and the turbine-room roof have been made of monolithic concrete to offer protection from debris in case of military attack. Fireproofing the roof asphalt is incidentally afforded in the turbine room. Roof asphalt will not leak and augment a turbine oil fire.

Boiler-Room Ventilation

The approximately one per cent of economically unavoidable heat loss from boiler-room apparatus is conserved to a major extent by introducing all combustion air by six large propeller type fans into the top of the boiler room. Since this low-level heat competes with extraction steam in heating combustion air, the net saving is approximately one-quarter per cent. This is closely adequate to justify the extra cost of housing the complete boiler plant, with all the other appreciable benefits of shelter accruing without cost, as treated in the author's discussion of outdoor power plants at the 1953 ASME Annual Meeting.

Plant heating, especially during construction before infiltration is minimized, is assisted importantly by avoiding the substantial suction that normally exists at lower levels. These large fans are specified to maintain about one-quarter inch pressure at the top of the boiler room, thus avoiding the stack-effect that ordinarily causes low levels to be poorly heated.

The circular motion at the top of the boiler room caused by locating the fans at opposite corners aids in mixing the cold incoming air with the heated boiler-room air and thus causes reasonably uniform temperatures throughout the boiler-room height. This contrasts with the usual considerable temperature gradient existing in typical boiler rooms.

Though the forced-draft fans are located near the boiler-room basement, where their discharge ducts are favorably short, their inlet air contains essentially all the boiler-room heat losses.

Substantially lesser preheating apparatus is needed for winter-time conditions, to avoid air-heater clogging, than with outdoor installations. Cleaner outside air, from the higher level, is of minor value.

Service-Water Strainer Experiences

The usual practice of taking backwash water from the system served has the double handicap of taxing the system when it can least afford it, and of permitting but a relatively low backwash flow rate. An air-water accumulator plan has proved that both of these demerits are avoided. With this system water slowly accumulates in a closed tank. As it fills the tank it compresses the air trapped above it. When the backwash valve is opened this air pressure forces the water out at a high flow rate. Through permitting a high backwash quantity this system allows using a very large screen area, and is thus further conducive of labor-saving and cleaner water. Entire plant impairment or outages have been known to result from service-water straining troubles.

Backwashing the strainers once each shift normally, and oftener in proportion to the amount of debris separated by the traveling screens abnormally, proved better than using pressure drop as the criterion. Al-

though considerable weeds and very troublesome industrial waste were experienced, at least two months' operation has occurred without opening the screens.

Boiler-Feed Pumps

By omitting Port Washington's turbine-driven pump and using two half-size pumps instead of Port Washington's approximately three-quarter size pumps, Oak Creek's feed-pump equipment costs per kw were reduced to half of Port Washington's.

Low usage of the Port Washington turbine-driven pumps and provision of four relatively independent sources of auxiliary current for Oak Creek seemed adequate bases for omitting the turbine drive. Without steam drives for other auxiliaries there is limited value of steam-driven boiler-feed pumps.

Dual boiler fans and condenser pumps, each of approximately half capacity, are generally accepted. The improved reliability of boiler-feed pumps, and the similar ability to carry two-thirds to three-quarters full output with one pump, due to reduced flow resistances, prompted the same dual auxiliary plan for Oak Creek boiler-feed pumps as with usual boiler fans and condenser pumps.

Two half-size boiler-feed pumps were further encouraged by the opportunity of reducing boiler pressure slightly to enable one pump to carry three-quarters load. Purchase of a spare internals assembly for the four pumps of two units, regardless of 200 psi difference of boiler pressure, was another factor in reaching the decision. Substitution of these parts is made in a few hours.

No experiences to date have required more than two half-size pumps.

Boiler Feed-Water Regulation Valves

To avoid check-valve failure causing feed-pump reversal and possible destruction the regulating valves were located at the discharge of each boiler-feed pump. Complete closure of its regulating valves before stopping either pump removes the need of dependence upon check-valve closure.

Check-valves are ordinarily highly reliable, but their failure has been experienced on two occasions at Port Washington notwithstanding careful maintenance practices. On both occasions, previous training of the operators caused immediate detection and correction. Placement of less dependence upon operating expertness seemed prudent.

Maximum pressure on the high-pressure heaters is reduced substantially by locating the feed-water regulating valves at each constant-speed feed pump. Starting and stopping of individual pumps can be accomplished with less flow variations. Fewer high-pressure header valves are needed. The regulating valves operate at lower water temperatures and with less temperature range, thus assisting their reliability.

Coal Storage

Cost of moving coal is approximately proportional to the distance moved. This encouraged a design that minimized moving distance.

A 900-ft by 900-ft dock, with a maximum pile height of 100 ft for the ultimate site development, was found most economic after many studies. The 100-ft height minimizes the hauling distance and the length of the underground conveyor. Three-quarters of the coal gravitates into this conveyor upon being delivered by the self-unloader boat.

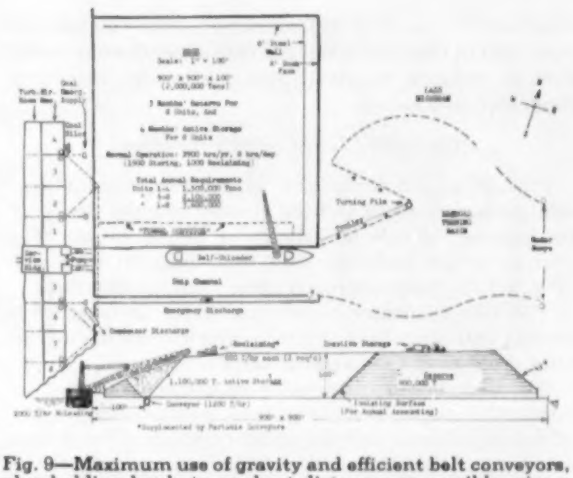


Fig. 9—Maximum use of gravity and efficient belt conveyors, plus holding hauls to as short distances as possible, give a smooth-flowing, relatively inexpensive coal-handling system

The three-months' "inactive-storage" reserve coal for each unit, possibly used no oftener than 20-year frequency (based upon Port Washington experience), is located farthest from the dock conveyor, Fig. 9. It is hauled there with a large wheeled scraper which packs it firmly to insure against heating. The three months' "active" storage during wintertime non-navigation is stored between this pile and the conveyor. Annual "clean-up" of this active-storage coal for accurate coal quantity accounting can be accomplished.

A 200-ft average movement distance for the ultimate development is indicated by Fig. 9. The use of portable conveyors, also utilized with bucket elevators to serve the bunkers above the mills for emergency coal supply, is expected to limit the moving cost over this relatively short distance to a favorably low amount.

"Fair-Weather" Coal-Boat Slip

Water-borne coal is usually of minimum expense, but the high cost of conventional harbor facilities on the Great Lakes solely for receipt of coal cancels the savings of efficient transportation. Port Washington plant experience suggested that simply an unprotected slip would be practical at Oak Creek because of the possibility of loaded coal boats from South Chicago bypassing the fair-weather facility during unfavorable weather and unloading within the Port Washington harbor. Study with the marine transportation company serving Port Washington confirmed that the plan was practical.

During the first year of operation only one bypassing occurred, and the docking plan proved wholly desirable. A 2000-ton-per-hr unloading rate, causing but 4 to 5 hours' docking time, ordinarily permits reliable weather predictions. The practice of turning-around before entry aids rapid departure to the safety of the open lake or to the shelter of the Milwaukee harbor 15 miles away. The ship channel serves the second purpose of a deep-water intake for the condensers, affording cold water to assist in maintaining the annual average of 0.6-in. Hg absolute turbine exhaust pressure, and in melting ice that otherwise can threaten plant shutdown on occasions.

Time and temperature difference for melting ice become very high in this case when the rate of condensing water flow is reduced to about one-quarter by throttling condenser inlet valves.

Centrally-Located Service Building

Production efficiency and isolation principles urge minimizing distances and the number of units that may be impaired simultaneously by a single cause. The central service building, with four units on each side (Fig. 9, left), helps approach these ideal specifications.

The two condenser circulating water systems, each serving four units have diversity which operating experience rates as of considerable value.

The uncertainty of tunnel sizes and designs that accompanies unplanned extensions often prompts the added investment and operating expenses of employing smaller, and thus more, units of auxiliary equipment.

Centralizing all electrical controls for eight units in one room may seem undesirable. Proper ventilation protective against the consequences of electrical fires appears adequate to permit the operating economies of this centralization.

Expanding mechanical and electrical shops, employee rooms, storerooms, etc. with each unit results in small, inefficient, and costly-to-operate facilities. Centralizing these functions has many operating advantages. Employee rooms can be air conditioned more readily in a central building than if scattered.

Boiler Experiences

Start-up. After Port Washington practice, acid treatment and alkaline boil-out were omitted. Experience with the Port Washington units showed repeatedly that there was little value of scrupulous pre-cleaning of the boiler if all other parts of the steam cycle, piping, turbine, condenser, heaters and tanks were not similarly cleaned. Oil and silica in quantities were ordinarily flushed into the boiler for the first week of operation. Liberal blow down during early operation, at relatively low and gradually increasing pressure and load, is considered most practical and has been followed for the recent units. Not until boiler water is totally non-foaming and its silica content is down to two or three parts per million is full load carried. Experience indicates that preliminary boiler cleaning does not advance this time, but instead delays it if the boiler erection determines the operating schedule.

Piping blow-out was thought prudent regardless of careful cleaning before erection. Compressed air in the boiler and high-pressure piping, released through a 6-in. quick-opening valve and 6-in. temporary piping, was employed to blow-out the reheater piping. Then the reheater system was filled with 100 psig compressed air to blow-out the high-pressure piping and superheater into the boiler with open manholes.

Vital to the success of any blowing-out is the need of a very high mass-flow rate. The carrying capacity of a 200-mile-per-hr gale, which will move large objects of high density, occurred during the initial part of the blows. That it was adequate was indicated by perfect condition of the high-pressure turbine blading after operation.

Tube Rupture. Seven hours' operation with a boiler tube rupture caused by an erection error, wherein a tube-end shipment cap had been welded into a joint, demonstrated a merit of the controlled-circulation boiler that is of considerable value. It contrasted greatly with the immediate forced outages of high-pressure natural-circulation boilers upon rupture of their 3-in. tubes. A $1^1/_2$-sq in. hole in the $1^5/_8$-in. controlled-circulation tube at 1500 psig caused loss of 50,000 lb per hr of water and steam, as compared with approximately total feed-water-flow loss upon rupture of a 3-in. boiler tube. The ability to continue output until other apparatus can be started from "cold" is of appreciable value.

Shut-Down Time. Forced circulation was also found of value upon an outage to repair a field weld. With natural-circulation boilers, sustaining the normal cooling rate of 35 F per hour becomes difficult below approximately 200 F because water circulation rate becomes low. With pumped circulation, the convection tube banks continue cooling with high effectiveness until room temperature is approached closely. With the entire periphery of the drum cooled by forced circulation, the cooling rate can be three, and possibly more, times that of the natural-circulation boiler, with still more rapid cooling near the end of the process.

Furnace Experiences

Furnace cleanliness experiences reflected the relatively low heat release per square foot of furnace heat absorbing surface (65,000 Btu per hr), the favorable location of the primary cooling surfaces, and the cleanliness aspects of the vertically-downward firing.

Hand cleaning has been totally unnecessary throughout the experience to date (April 25), despite using mid-Western coal of 2050 F ash softening temperature. For all of the period, soot blowers were unavailable. Absence of any deposits, other than dust, is shown by Fig. 5, after two months' operation without cleaning. This seems truly a self-cleaning furnace.

Superheated-steam temperature tendency to exceed 1000 F at the higher loads, when the flames could not be driven to the bottom of the furnace, was corrected by tilting the burner tips 7 degrees toward the front furnace wall. This experience suggested that for short or overnight stops, when high steam temperature is desired immediately upon resuming operation, rotation of the burners 180 degrees to get the flames outside the platens will be effective in raising steam temperatures substantially. Reheat steam temperature is responsive to differential firing of the middle and end cells, for which automatic control of steam temperature and excess air is provided.

Condenser Experiences

Condenser clogging with industrial waste stopped production almost daily until a backwash system was installed one week end. The initially-installed two valved inlets assisted importantly. Adding a partition in the inlet water box, a partial butterfly valve in the outlet pipe, and valved connections from the two inlet sections to a 24-in. discharge pipe, caused backward flow in alternate halves of the condenser, with the industrial refuse being flushed to the discharge tunnel. This relatively minor installation has served perfectly, and will be installed in future units because of the realization that entire plant output can be hazarded on occasions by a relatively small opening in the traveling screens.

Subsequent measurements at the top of the traveling screens proved that a $^1/_2$-in. by 10-ft slot existed at their lower, "boot," ends, through which the slightly heavier-than-water debris bypassed the $^5/_{16}$-in. mesh screens. These excessive clearances have since been corrected.

The overflow standpipes from the condenser circulating-pump discharge manifold that prevent overloading of the motors functioned frequently during the period of condenser clogging. These "safety-valves" seem a necessary part of an installation of this nature.

Not until more units are installed can low flow resistance of the system and its total desirability be confirmed. Experience to date suggests that it will be efficient and satisfactory.

Turbine Experiences

Initial loading of the turbine occurred on September 30, 1953. After $5^1/_2$ days of low loading, at low boiler pressure to limit dirtying of the blading with silica deposits and to eliminate oil from the entire system, sudden excessive vibration occurred at 22,000 kw that required shutdown and dismantling of the high-pressure and intermediate-pressure turbine sections.

Operation resumed November 30. Load and pressure were gradually raised when boiler-water silica and foaming tendency were obtained favorably low by high blowdown rate. One ppm silica is normally maintained at present. One-half ppm is expected when a blowdown heat-exchanger with low terminal temperature differences is completed and operating. Rated load was carried initially on 12-21-53.

In no way has the developmental nature of this new design impaired performance. Stage temperature-pressure data are evidence of high efficiency. Plans contemplate internal inspection of but one of the three sections at a time during routine one-week annual outages. This ability and Port Washington extensive experience suggest that 11 days of outages every year, of which 6 will be Saturdays and Sundays, will be adequate. The resulting promise of simply 5 "week-days" of outage per year is encouraging.

Boiler-Room Ventilation Experiences

Fair uniformity of boiler-room temperature is shown by the data of Table I. In general, it shows approximately 70 F average at the top of the boiler room when outdoor temperature was 20 F; the highest average temperature of 82 F at approximately one-third the boiler-room height, and 73.5 F entering the forced-draft fans at only 10 per cent of the height. This contrasts markedly with usual gradients in high boiler rooms.

Mixing at the upper levels adequately avoided any excessively low temperatures near the combustion-air fan discharges. Sub-zero temperatures caused no troubles. Without these fans, the lower levels of the plant would have been difficult to heat, especially during construction of adjacent units. On one cold-weather occasion when half of the fans were rendered inoperative, the turbine-room suction, and construction openings, caused 24 F ambient, which froze low-vacuum-trip lines and caused a 7 minutes' outage. Full fan operation normally caused warming of the turbine room through openings from boiler room.

The 53.5 F combustion-air temperature rise saved in Table I represents over one per cent of the boiler heat input. It attests to the economics of shelter.

TABLE I—UNIFORMITY OF BOILER ROOM TEMPERATURES

Combustion Air Introduced Into Top of Boiler Room With Rotary Motion. Data of January 22, 1954. Temperature Outdoors, 20 F; 10 Miles per Hour E. Wind. No Supplementary Boiler-Room Heating.

	Side of Boiler Room				
Elevation, ft	West	East	North	South	Average*
123	75	81	61	60	69†
113	—	93	64	70	76
102	69	81	70	76	75
94	—	76	62	80	73
86	—	76	52	75	69
81	82	—	76	68	72
72	76	76	77	70	75
55	83	88	84	66	80
45	85	95	86	65	82
33	91	82	82	69	81
20	76	73	72	65	74
8	70	61	61	67	63
FD fan inlets (elev. 20 ft)				73.5 F	
Outdoor				20 F	
Heating by "radiation losses"				53.5 F	

* Approximately 15 locations at each elevation.

† Lowest temperatures on passageways near fans were: North 40 F; South 56. On north side, surge tanks reduce entrainment air, thus explaining the 16 F difference.

Coal-Handling Experiences

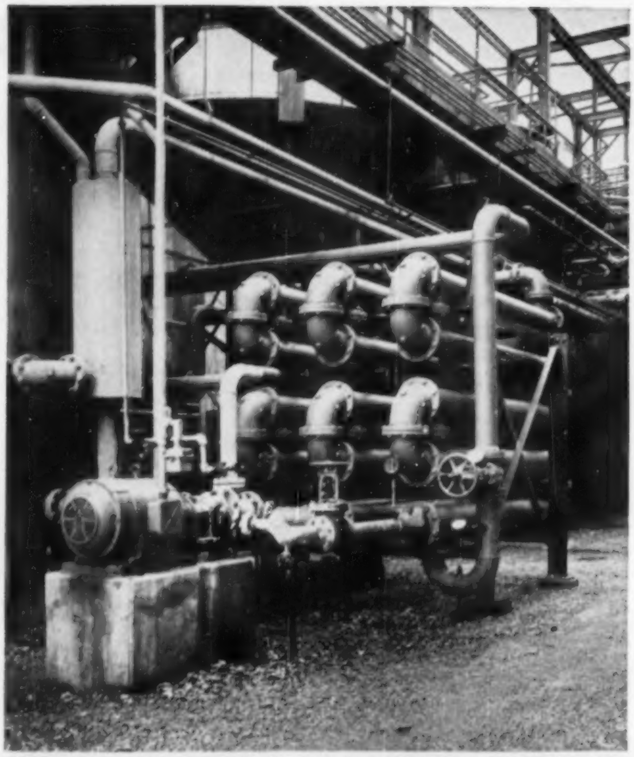
The fair-weather boat slip handled some forty 6500-ton cargoes during mid-summer without incident. Simply once did bypassing to Port Washington occur, and that was due to a question concerning dredging early in the period. More bypassing is expected when spring and fall shipments occur, but there is nothing to indicate that the plan is other than thoroughly practical. The time required from nearing the turning pile to the start of unloading is one-half hour. Departure is made in about 5 minutes. The total time is less than one-half that at Port Washington. On the relatively short haul from South Chicago this lesser time permits over 2 per cent more tonnage capacity, which adds substantially to the net income of a ship. Calculations indicate that on a short haul, because of the short unloading time of a self-unloader ship, it can transport coal at less cost than can a bulk freighter. This is not true, of course, for long hauls.

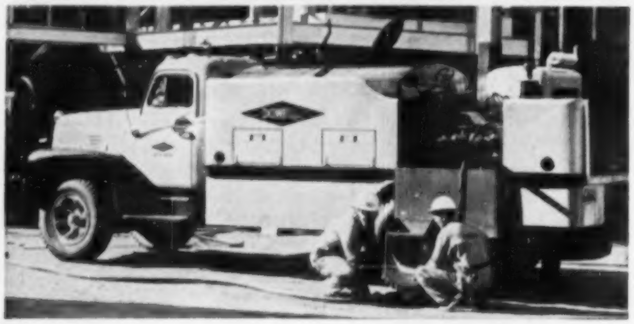
Spontaneous heating of the 4 per cent sulphur West Kentucky coal caused dustiness and vapor troubles when conveying it into the plant after its long period of storage, worsened by the two-month turbine outage. The southern Illinois coal of $1^1/_2$ per cent sulpur, packed into the inactive storage at the far extremity of the dock, remained positively cold. For the unpacked active-storage coal, early plans of injecting flue gas via drains along the conveyor tunnel will be consummated this season, principally to reduce the need of two-month "clean-up" of the pile above the conveyor as has been found desirable with the 4 per cent sulfur coal at Port Washington. Further, this higher sulfur coal will be burned during the navigation season, and the lower sulfur coal will be stored for the winter period. Port Washington experience affords good assurance that a 100-ft-high pile will be thoroughly practical. Height reduces moving distance.

Conclusions

In general, the major objectives of the several new designs were reached without more than the normal trouble that usually accompanies new power plants. The principal troubles were experienced with conventional apparatus or with parts in no way influenced by the change in design.

Experienced engineers are at your service day and night. They diagnose the trouble, prescribe and administer the cure for maintenance cleaning problems.





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The Voikka Steam Station A Modernized Industrial Steam Plant In Finland

By GUNNAR HÖGNÄS Operating Engineer, Kymmene Aktiebolag

This is an interesting account of power plant problems encountered in a large paper mill in a country which must import most of its fuel supply. Reasons for selecting a pulverized-fuel-fired boiler are enumerated, and operating experiences are related.

FINLAND is not only the Country of a Thousand Lakes. It is also known for its extensive forest. About 70 per cent of its territory, or approximately 21,000,000 hectars, is covered with forests. Of this about 57 per cent is owned by private persons, about 34 per cent by the Government, about 7 per cent by industry and the remainder belongs to municipalities and parishes. Forests give raw material for the most important of the country's industries, the wood industry. More than 80 per cent of Finland's exports consists of pulp, paper and timber products.

Kymin Osakeyhtiö-Kymmene Aktiebolag is one of the foremost pulp and paper companies in the country. The company was founded in 1872 when Finland's woodworking industries were first beginning to develop. Kymmene Aktiebolag owns several mills, the most important ones being situated along the Kymmene River, a river abounding in waterfalls and a center of one of the most vital industrial areas in the country.

The total yearly production of the company is at present approaching 180,000 metric tons of paper (of this about 125,000 metric tons is newsprint) and 100,000 metric tons of sulfite cellulose, of which more than half is used in the company's own paper mills. Cellulose production will, in the near future, be increased to about 150,000 metric tons. Apart from this about 11,000 metric tons of cardboard and pasteboard, 25,000 standards sawn timber, 25,000 metric tons chemical products and 20,000 metric tons metal products are produced. The company owns a peat bog producing about 35,000 metric tons of peat a year. In addition to this it should be mentioned that Kymmene Aktiebolag has at its disposal approximately 65,000 kw of developed waterpower.

Voikka is one of the two mills in the municipality of Kuusankoski on Kymmene River. The Voikka mills include a paper mill, where practically the whole of the company's production of newsprint is concentrated,

Location of Voikka Steam Station

Exterior view showing characteristic Finnish landscape

as well as a sulfite cellulose mill with an annual production of 50,000 tons.

Voikka paper mill was enlarged and modernized between the years 1934 and 1936. Two newsprint machines with a width of 212 in., manufactured by the English firm of Walmsleys (Bury) Ltd., were installed. These machines have been improved, especially since the war, so that it has been possible to increase their speed up to approximately 1440 ft per min. Apart from these two up-to-date paper machines, Voikka has four smaller machines of older design.

In the cellulose mill there are four digesters of 9700 cu ft each for indirect cooking.

Voikka has two steam turbines; one backpressure-extraction turbine of 9000 kw and one condensing turbine of 10,000 kw.

Steam Consumption

The steam plant must provide steam for paper machines, cellulose digesting, heating, etc. In spite of the fact that Kymmene Aktiebolag, as mentioned above, owns hydroelectric power stations of considerable capacity, steam is also required for generating electric power, and during years of reduced water supply the company is largely dependent on steam power. The situation is further complicated by the fact that Kymmene River basin has few or no possibilities for storing of water.

Approximately 110,000 lb per hr of back-pressure steam at 17 psig is required. Consumers are the two big paper machines and various kinds of heaters. The older paper machines, cellulose mill, etc., as well as the feedwater deaerator and heaters use steam at 50 psig, which is the extraction pressure of the turbine. The requirement for extraction steam is about 132,000 lb per hr at full winter production. The total requirement for steam, excluding the condensing turbine, is about 242,000 lb per hr at full production. As the back-pressure turbine has a maximum requirement on the high-pressure side of 199,000 lb of steam per hr at an admission pressure of 430 psig and temperature of 750 F, there is no possibility to make use of the entire steam requirement of the plant for generating of cheap back-pressure power.

At full load the condensing turbine uses nearly 100,000 lb per hr of steam at 430 psig and 750 F. During the low-water period, when there is a shortage of power and when the generating capacity of the condensing turbine is also required, the total requirement for steam in Voikka increases to 342,000 lb per hr.

Fuel

Coal is the principal fuel consumed by Finnish industry, although recently fuel oil has also gained rather extensive use. While there is an abundance of forests in Finland, wood is considered more valuable as a resource for the pulp and timber industry than as a fuel. What is burned is mainly in the form of waste timber, sawmill waste, barking-drum waste and other timber refuse. The country has ample resources of peat bogs, but peat has, at least until now, been cut only to a limited degree. In the field of peat cutting Kymmene Aktiebolag has been and still is one of the pioneers. The whole of the company's peat production is burned in its own steam plants.

Finland has no coal or oil deposits of its own and is completely dependent on imports. The choice of suppliers is dictated by changes in commercial possibilities, and the obvious result is that the quality of the fuel varies. The country imports coal from England, U.S.A., Germany, Poland and other areas. The table below shows the extensive variation in coal qualities with which the Finnish consumer has to reckon:

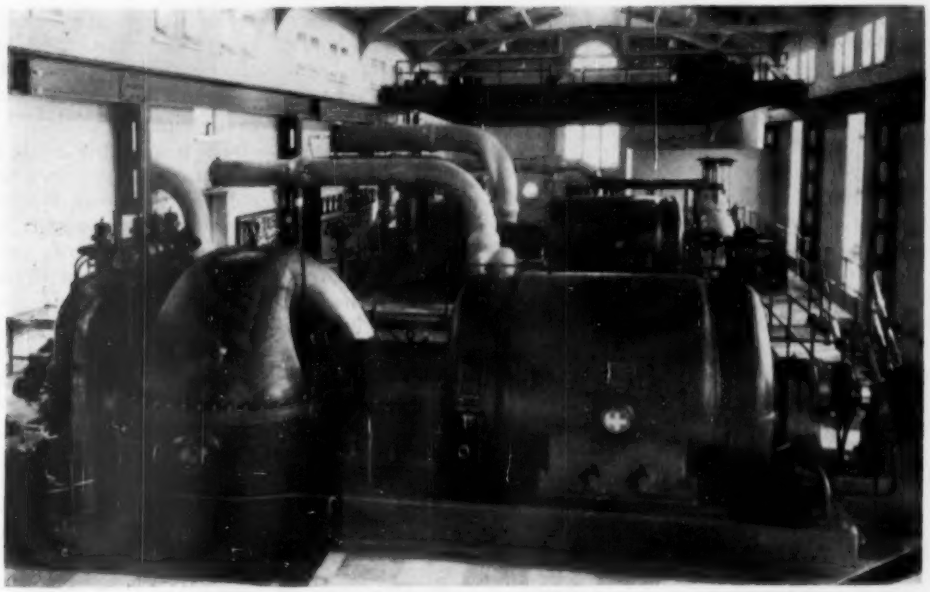
	Average	I Polish Coal	II English Coal
Total moisture, %	4–16	14	12
Inherent moisture, %	4–7	6	4
Ash (dry basis), %	10–18	14	9
Beginning of melting, °F	1922–2282	1967	2012
Fusion point, °F	2102–2462	2147	2192
Volatile matter, %	30–45	33	35
Sulfur, %	0.8–2.5	1.5	1.5
Sizing (duff and slack)	0–1	0–$^3/_8$"	0–1"
Hardgrove Index	50–70	50–58	52–60
Air dry calorific value, Btu per lb	11,500–13,900	11,500–12,400	11,900–13,000
Net calorific value, Btu per lb	10,100–13,000	10,100–11,500	11,000–13,000

Fuel oil is also imported from different countries. Below is an analysis of a common grade of oil.

Spec. gravity, at 68 F	0.95
Viscosity, at 122 F, deg Engler	11.5
Viscosity, at 212 F, deg Engler	2.3
Flash point	239 F
Solidification point	57 F
Sulfur content, %	1.0
Ash content, %	0.2
Moisture content, %	0.9

Boiler Plant

Voikka has four boilers which have been in operation for some years. They are all built for natural draft from a 380-ft stack. In the late 1920's when the last rebuilding of the boiler plant was started, steam conditions of 500 psig, 750 F were adopted. Boiler No. 3, which was built by Vickers Boiler Company Ltd., London, in 1927 is one of the oldest pulverized-fuel boilers in the country and was the first boiler in Finland to have a pressure as high as 500 psig. The furnace has a bottom screen, three air-cooled walls and a water-cooled rear wall. The six burners are placed vertically; the boiler is thus a typical example of a pulverized-fuel installation of that period. The original pulverized-



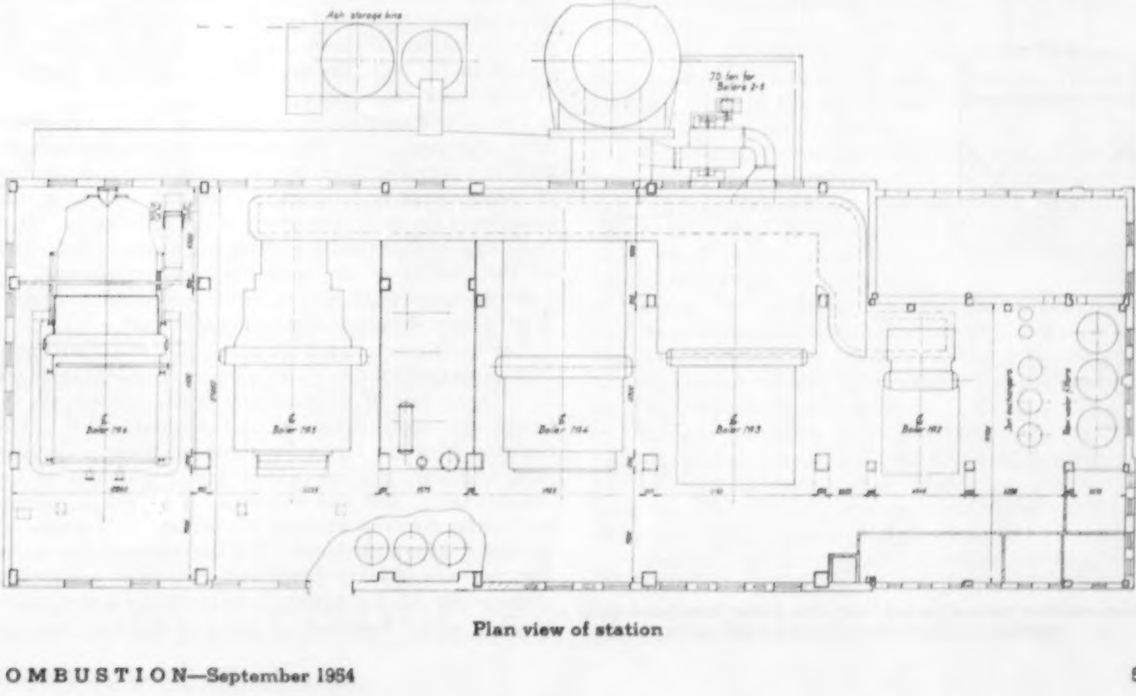
View of turbine room

fuel equipment of German Rema manufacture was replaced in 1950 by a Kennedy van Saun unit. The maximum continuous steam capacity is 77,000 lb per hr.

Experiences with the first pulverized fuel boiler were not very successful. The boilers installed next were equipped with chain-grate stokers. Boiler No. 4 was built by the German firm Krupp in 1929 and boiler No. 5 by British Babcock & Wilcox in 1935. The maximum continuous steam capacity is 77,000 lb per hr.

In 1942 boiler No. 2, which is a two-drum, bent-tube boiler, manufactured by the Finnish firm Tampella, was installed in the oldest part of the boiler house. It was equipped with a step-grate, and sawmill waste, barking-drum waste, peat, etc., are burned in it. Its capacity is approximately 33,000 lb of steam per hr. Boiler No. 2 replaced two small step-grate boilers.

At the same time as boiler No. 5 was installed, the boiler house was enlarged and space was reserved for a boiler of the same size as boiler No. 5. By the late 1930's the boiler reserve was at times non-existent, but World War II prevented the installation of planned boiler No. 6. After the war, when the production of the mills was continuously increased, the situation became untenable. The years 1947 and 1948 were most difficult. At that time an abnormally long period of low water was experienced throughout the country with considerable shortage of electric power. The shortage was felt even more, as there had not yet been time enough to replace



Plan view of station

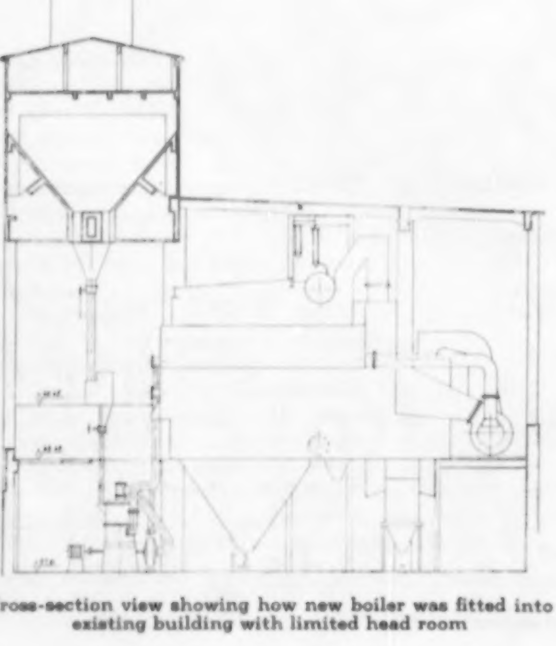
the hydroelectric power stations which had been lost to Russia in connection with the ceding of territory. For the condensing turbine there was under most favorable conditions steam for only half of its capacity. The power deficit had to be bought from outside at a high price, and this was not always possible. The smallest disturbance in the boiler house caused a decrease in the factory's production, and disturbances in the overloaded and dirty boilers was innumerable.

The management of the company did all that was in their power to bring about an improvement. As soon as circumstances—especially the foreign currency situation—allowed, a decision was made to buy a high-efficiency boiler. More than anything else it was the loan from the International Bank that enabled this purchase to be made. Today, 18 years after space had been set aside for a new boiler, a boiler of quite different design and of completely different qualities has been erected in this area.

The New Boiler

Studies indicated that the capacity of the new boiler should be in the range of 155,000 to 175,000 lb of steam per hr. This capacity was considered suitable partly in view of the actual demand and partly in view of the future when the full demand of the factory was to be satisfied by two similar units, possibly with a third one in reserve. The boiler was to be designed so that the steam pressure at superheater outlet was 910 psig and the steam temperature 900 F. These steam data are considered the most advantageous in Finnish circumstances for industrial plants of the size described which burn both coal of the extremely varying quality and fuel oil.

There were very severe space limitations, particularly with respect to headroom. The boiler had to be fitted into an area originally intended for a unit of much smaller size.



Cross-section view showing how new boiler was fitted into existing building with limited head room

The buyer preferred to place an order for a pulverized-fuel-fired boiler. It is true that a chain-grate-fired unit might have been considered but a pulverized-fuel boiler was preferred, for the following reasons:

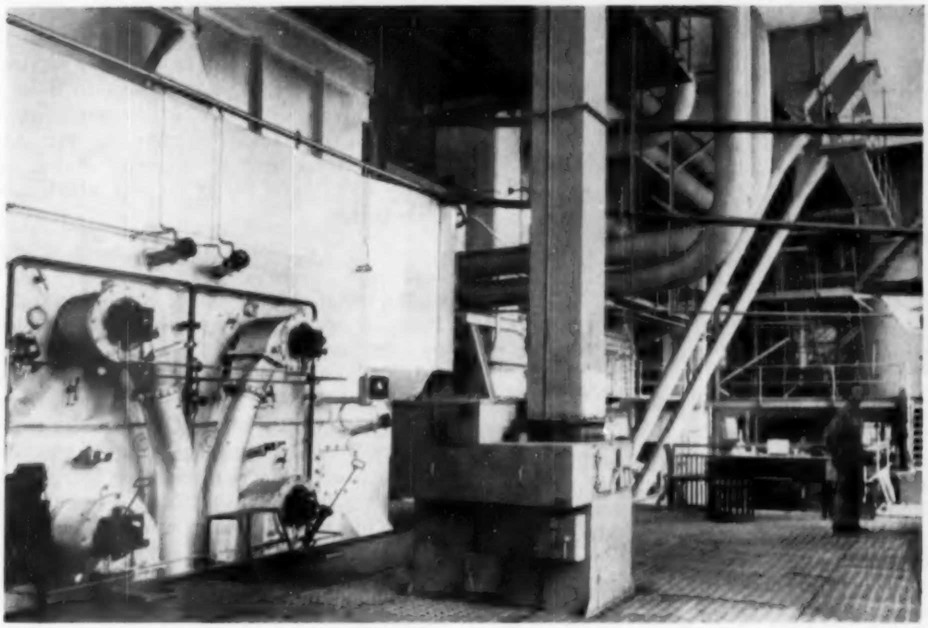
(1) **Variations in the quality of coal.** The necessity to be able to burn low-quality coals during long periods must be taken into account. It is true that coal of lower quality than that for which the boiler is constructed can be burned also in chain-grate boiler, but it is inevitably done at the cost of a more substantial decrease in efficiency and capacity than is the case with a pulverized-fuel boiler under similar circumstances. Above all, it is the losses due to carbon in refuse that rise disproportionately in a stoker-fired boiler. It can hardly be doubted that, under unfavorable circumstances with respect to fuel, a better boiler availability can be maintained in a pulverized-fuel boiler than in a chain-grate boiler. Ash deposits on the tubes in pulverized-fuel boiler are considerably less serious than in a chain grate boiler. This has been proved in the years during and after the war as conclusively as can be desired. As noted previously, both types of fuel burning are employed by the plant. Only inferior qualities of coal could be obtained during this period, and the boilers were pressed to the utmost.

(2) **The rapid variations of steam load.** As the major portion of the steam goes to the paper machines, the variations of the steam load may be very rapid and rather extensive. A pulverized-fuel boiler can cope with these variations better than a step-grate boiler; this, however, is true only down to a certain limit. If the minimum limit for the capacity of the pulverized-fuel boiler is passed, the balance may be regulated by taking part of the burners out of operation. In a fully water-cooled furnace there is always a danger of an unstable coal flame and incomplete combustion when the furnace load goes below a certain minimum.

(3) **Use of automatic control.** Pulverized-fuel firing is more suitable for automatic combustion control than chain-grate firing. Automatic control only can maintain the highest possible average efficiency at the wide variations of steam load. In Finland, where the cost of fuel is high, the question of automatic control is of exceptional importance.

The above-mentioned advantages were considered more important than the drawbacks that undoubtedly go with a pulverized-fuel boiler. Extensive consumption of power, wear and threat of explosion are, as a rule, considered the most important of the drawbacks. How considerable these disadvantages are depends essentially on the quality of the pulverized-fuel equipment. As a disadvantage must also be mentioned minimum rating noted above, if only pulverized coal is used.

The space reserved for the new boiler was inadequate. It was originally intended for a boiler of 88,000 to 99,000 lb of steam per hr with natural draft. Above all, the height appeared insufficient, it being only 66 ft. This contributed to the buyer's decision to choose a Combustion Engineering Type VU-50 boiler which is of low construction. But this was done, it should be pointed out, without modification of the demands for secure operation and high efficiency. On the contrary, the manufacturer was able to point out the great advantages of the boiler in both respects. As the boiler is of standard type, of which hundreds of units of different sizes are



Firing aisle showing burners and coal feeder

in use, it was easy to get references. During periods of very low steam demand, one of the old boilers, one of which at least must be on line, could take the load. Under such circumstances it was considered impractical to heighten the concrete roof, which the other boiler types called for and which would have increased the cost considerably.

The design pressure of the new boiler is 1000 psig. To begin with, the operating pressure at the superheater outlet will be about 450 psig and the steam temperature 750 F. As it is, the boiler will be in operation simultaneously with the old boilers and steam turbines. In the future the steam pressure will be increased to 910 psig and the steam temperature to 896 F. In both cases the capacity is, at continuous operation, 160,000 lb per hr. Conversion to a higher steam pressure and temperature calls for enlargement of the superheater as well as raising the feedwater temperature.

Characteristic of "C-E Vertical-Unit Boiler, Type VU-50" is its compact design which, among other things, is without outside downcomers and risers. It is a two-drum boiler with a vertical tube bank where the downcomers consists of 2-in. tubes and the rest of 3-in. tubes. The heating surface of the boiler proper is 16,065 sq ft.

The furnace is fully water cooled with the tube bank of the boiler as a rear wall. Screen tubes, which at the same time act as risers for the walls and the roof, protect the ash pit below against overheating, and cool the ashes so that sintering down in the ashpit is avoided. The heating surface of the cooling walls is 4450 sq ft and the volume of the furnace is 10,320 cu ft which at full load is equivalent to a furnace load of approximately 20,500 Btu per cu ft per hr.

Superheater

The superheater is of Elesco type with the elements welded together with headers. This suspended, inter-bank superheater is supported by steel construction, located entirely outside the boiler. It is connected with the steam drum by sixteen 3-in. tubes and spread out over the entire length of the steam drum. The heating surface of the superheater is 3525 sq ft. Superheat temperature is regulated by water-cooled dampers which allow a part of the flue gases to bypass the superheater.

The economizer is rather small with only 1828 sq ft heating surface. It is of Elesco finned-steel-tube construction. The feedwater inlet temperature is 284 F. The full operation pressure 910 psig corresponds to the feedwater temperature of 338 F which requires a feedwater heater with 100-psig steam.

The tubular airheater is divided into two sections and has a heating surface of 37,100 sq ft.

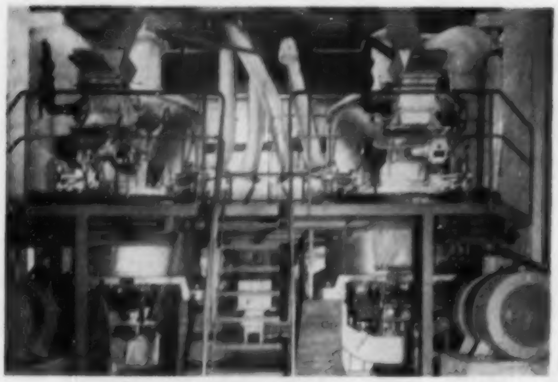
The dust collector is located behind the first part of the air preheater and is of Western Precipitation manufacture. It is of the Multiclone design equipped with 6-in. × 24-in. collecting tubes.

Induced- and forced-draft fans are both of Westinghouse-Sturtevant manufacture for 89,500 cfm at 13-in. w.p. and 57,500 cfm at 10.55-in. w.p., respectively. The induced-draft fan is equipped with a hydraulic coupling which can be controlled from the panel board on the operating floor.

The coal bunker forms a part of the building and is cast in concrete. It has a capacity of 150 tons of coal which is sufficient for about one day's consumption. The coal passes through an automatic coal scale supplied by Richardson Scale Company.

There are two C-E Raymond bowl mills having a capacity of approximately 13,000 lb of coal per hour with 14 per cent moisture and 50 Hardgrove grindability. Coal from the mill exhausters is carried to two C-E type R burners in the front wall of the furnace.

A Peabody oil-burning set furnishes the fuel oil to C-E type RO mechanical-atomizing oil burner located in the center of each pulverized-coal burner. About one-half load of the boiler can be maintained with oil.



Installation of bowl mills

Vulcan soot blowers of the retractable and the rotary type are installed. The soot blowers are controlled automatically from an electrically driven center.

Motors for the induced-draft fan and the coal mills are of the squirrel-cage type, manufactured by the Finnish firm O/Y Strömberg A/B.

The feedwater piping and steam piping, connected to the new boiler, are made by the German firm Mannesmann. The design of the piping was complicated by the necessity of having to adapt it to systems operating at two different pressures. The new piping must be partially connected to the present system which is based on 500-psig steam pressure and will not be revised for a number of years. It must also be possible to connect the newly built piping with minimum alterations to the new system which is based on 910-psig steam pressure. The new high-pressure pipe lines are completely welded; only a small number of valves, the main steam valve included, have flanged connections.

Instrumentation

The instruments and the control systems for the boiler are furnished by The Bailey Meter Company. The rate of combustion is controlled by a master controller which measures the steam pressure after the superheater. The master controller sends its impulses both to the fuel side (feeders for the mills, exhauster dampers and fuel oil control valve) and to the gas side. The latter is controlled by an I.D. damper. The boiler meter maintains proper relation between air flow and steam flow, thus making the combustion at every load as economical as possible. The boiler meter and the master controller are working together on the I.D. damper. The F.D. damper is operated by a furnace draft controller. In the future, the other boilers can also be controlled by the same master controller.

The feedwater control valve is operated by a Bailey three-element feedwater control system. This works by comparing steam flow and water flow and making a correction from the drum level.

The steam temperature is controlled by the superheater bypass damper. This controller gets its impulse from the gas flow and the steam temperature.

The temperature of the pulverized fuel on each mill is controlled by a temperature controller operating cold and hot air dampers before the mills.

In order to keep the temperature of the flue gases above the dew point at all times, the air can be recirculated in the heater by using an air bypass damper which is operated in response to flue-gas temperature.

To secure reliable and trouble-free service from pneumatic controllers, it is necessary to have a supply of clean oil-free air. This is accomplished by using a special instrument air compressor with carbon piston rings, manufactured by Ingersoll Rand. It has a capacity of 127 cfm air at 80 psig which is sufficient for three boilers.

Experiences with the New Boiler

The installation of boiler No. 6 was begun in March, 1952. It was done by the buyer's own men supervised by the superintendent of the boiler manufacturer (Mr. B. Duncan). We were able to start the boiler in February 1953. The operation was, during the first months, controlled by the C-E's service engineer (Mr. K. Andersson). The automatic control was adjusted by the Bailey Meters' service engineer (Mr. C. H. Norman) who controlled the operations for two and a half months.

The official boiler tests were run on the 24th to 28th of March 1953, under the supervision of the Association of Fuel and Power Economy (EKONO). The main tests were undertaken with Polish coal of the following qualities:

Total moisture	11.1%
Ash content	12.1%
Volatile matter	32.7%
Air dry calorific value	11,300 Btu per lb
Net calorific value	10,800 Btu per lb

The test results showed that the boiler, in most respects, met the requirements that had been expected from it. The efficiency was approximately 92 per cent (equivalent to approximately 88 per cent counted on the calorimetric value).

The consumed heat was divided as follows:

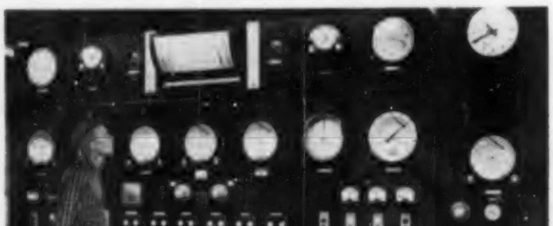
Preheating of water in economizer	2.5–2.3%
Evaporation	73.2–73.7%
Superheating of steam	16.3–15.7%

And losses:

Free heat in gases to the stack	5.5–5.0%
Amount unburnt in gases to the stack minus amount unburnt in ashes (the part that could be collected)	1.6–1.4%
Residue losses (in fly ash, soot, radiation and conductivity)	0.8–1.9%

The steam temperature rose to 780 F in spite of the fact that the bypass damper's baffles were fully open. The air temperature behind the air-preheater did not rise to the calculated 464 F, but stayed between 410–428 F.

The boiler has been in operation for about one year.



Panel control board for new boiler (No. 6)

Practically all the time we have been able to burn both pulverized coal and fuel oil simultaneously. This has naturally made the control easier, and the boiler has been capable of coping, without undue difficulties, with all the load variations of the boiler house. These variations are at times so extensive that they must be divided between two boilers, if pulverized coal only is used. In other respects the boiler has, with the exception of a few solitary disturbances, operated satisfactorily. The only considerable mishap we have experienced occurred when one of the burners was destroyed. A fire broke out around the pulverized fuel nozzle and the secondary air vanes. Pulverized coal had in all probability leaked out to the air chamber where a jet flame within seconds caused the destruction.

The air heater outlet has a tendency to plug up in its coldest part notwithstanding the fact that we have been running with the hot air recirculation damper open almost all the time. The tubes must be cleaned every three months. As the tubes are not of corrosion resistant material, we fear that this will become a source of trouble.

The operation of the boiler controls has been satisfactory. A well-planned maintenance program is essential for keeping such a complicated system of instruments in the best possible repair. During periods of extremely rapid load variation it is necessary to change over to manual control of the speed of the I.D. fan.

The secondary dampers around the pulverized-coal burners must be adjusted manually with major load variations. This is inevitable when pulverized coal is burned alone, if the best possible flame is wanted. In case of sudden and frequently repeated variations a great deal of trouble is caused by the manual control; at a sudden decrease there is impending danger of the flame going out. It has, therefore, been suggested to couple the secondary dampers as well to the boiler control. This would in all probability add to the security in burning pulverized coal alone.

Purification of Feedwater

Water in Finnish rivers and lakes is as a rule very suitable for feedwater. Hardness is approximately 1° dH (10 ppm CaO). Most of the trouble is caused by organic substances equaling a $KMnO_4$-consumption of 30–100 mg/liter. The silicate-content can also become troublesome. In the Kymmene River the $KMnO_4$-consumption is 35–60 mg/liter and the SiO_2-content 3–4 mg/liter.

In connection with the modernization of the Voikka boiler house, the feedwater treatment plant has been completely renewed. In the old plant, which was built by the German firm of Balcke in 1935, the hardness of the water was counteracted by the use of $NaOH$-Na_3PO_4 in the reactors. Deaeration took place in a vacuum. This purification method is inadequate for 910-psig boiler pressure.

In the new plant the organic matter is coagulated with aluminum sulfate as agent. The coagulants, together with impurities, are removed in the raw water filters which are filled with anthracite. The water goes through the Balcke ion exchangers, passes the blow-down and drain coolers as well as the preheaters and enters the deaerator at a temperature of about 175 F. After the deaerator NaOH is added which raises pH of the feed water to 9–10. In order to eliminate last traces of oxygen, hydrazine (possibly sodium sulfite) may be added here. This is not yet done at the low boiler pressure. Na_3PO_4 is fed directly into the steam drum.

To date it is impossible to determine how effective this purification method will be for a 910-psig boiler pressure, for which the purification plant is designed. Operating experience has shown it to be satisfactory for a boiler pressure of 500-psig. An inspection of boiler No. 6 after 5 months operation at the lower pressure disclosed no trace of deposits or corrosion.

Ash Handling

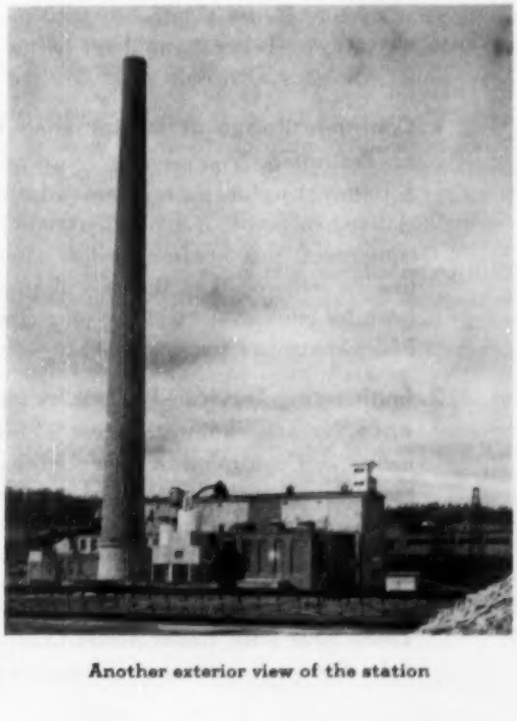
In chain-grate-fired boilers the ash goes through an ash spray. These wet ashes are taken in a van to an ash elevator which empties them into a separate container. The ash elevator, supplied by the German firm of Stohr, and the ash container are new.

When the decision was made concerning disposal of the dry fly ash, the choice was between a hydraulic and a pneumatic system. The hydraulic system could not be accepted for the following reasons:

The factory is situated along a river with a great number of industrial plants downstream. With the hydraulic system there is always a risk of contaminating nearby waters, and this threat is even greater if sulfite waste liquor is burned, for the ashes of this process coagulate very slowly. That possibility must be taken into consideration where there is a sulfite cellulose mill.

The company consequently decided upon a pneumatic ash-handling system. This has been delivered by The United Conveyor Corporation. The dry ashes are conveyed in a piping system by air flow produced by a steam-operated exhauster.

The consulting engineers for the modernization project were Stadler, Hurter & Co. of Montreal, Canada.



Another exterior view of the station

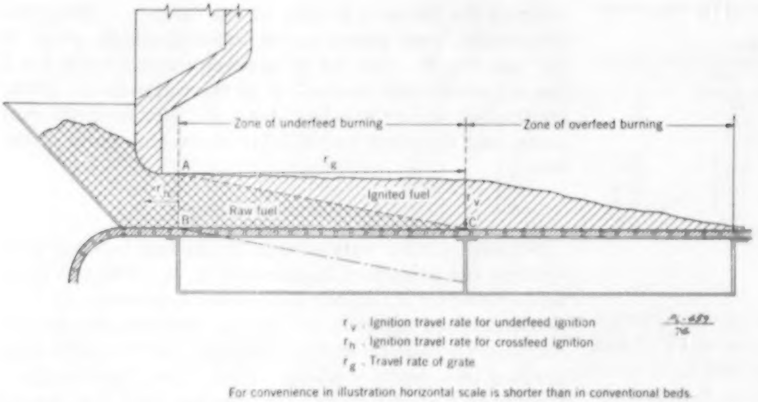


Fig. 1—Schematic drawing of a traveling-grate stoker pictures the ideal crossfeed ignition plane, AB, as contrasted to the actual, plane AC, caused by a moving grate

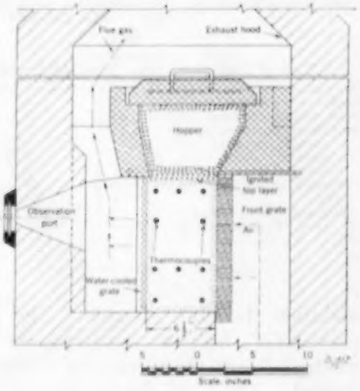


Fig. 2—Test furnace above directed air horizontally across fuel bed from plenum chamber

Pure Crossfeed Ignition in Fuel Beds

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Here, in the first factual data on record, the third method of fuel-bed firing, crossfeed ignition, reveals ignition rates that continue increasing at air feeds from 500 to 1200 lb per sq ft per hr, way beyond those of traditional grate burning methods hampered by lifting fuel beds. Further studies seem promising for this method where fuel bed can be any thickness and there are no moving parts.

VIRTUALLY no work was done on investigating the modes of burning on grates until H. Kreisinger, et al., made their classical studies at the Bureau of Mines in 1916.[1,2] While he and his co-workers were concerned with the characteristics of the overfeed mode of burning coal, P. Nicholls,[3] several British investigators,[4–7] and later Carman and Reid[8] devoted their interest to the problems of underfeed ignition and burning. But there remains still a third basic mode—crossfeed ignition and burning on which this paper now reports.

Crossfeed burning is characterized by the ignition plane moving perpendicular to the direction of flow of the air. Often this mode of burning is used, improperly, to designate the combustion process on a traveling grate. Referring to the schematic drawing of a traveling grate stoker, Fig. 1, ignition plane *A-B* represents ideal crossfeed ignition. Actually, the ignition plane inclines, as shown by plane *A-C*, owing to the horizontal movement of the fuel bed, and the mode of ignition and burning is underfeed. (We define the slope of the ignition plane as the angle whose tangent is r_v/r_g, where r_v is rate of ignition travel and r_g is the rate of grate travel.) Evidently, the ignition plane would approach the horizontal if the grate were speeded up. It would then resemble conditions in a pot-type furnace, which other investigators used for fundamental studies of fuel bed processes.

The conditions that produce ideal crossfeed ignition and burning on a traveling grate raise interesting considerations. Imagine that the fuel is burning under steady state conditions with a given grate speed and air rate, and that the ignition plane is that represented by plane *A-C*. Now progressively decrease grate speed but

[1] Kreisinger, H., Ovitz, F. K., and Augustine, C. E., "Combustion in the Fuel Bed of Hand-Fired Furnaces," *Tech. Paper 137*, Bureau of Mines, 1916.
[2] Kreisinger, H., Augustine, C. E., and Katz, S. H., "Low-Rate Combustion in Fuel Beds of Hand-Fired Furnaces," *Tech. Paper 139*, Bureau of Mines, 1918.
[3] Nicholls, P., "Underfeed Combustion, Effect of Preheat and Distribution of Ash in Fuel Beds," *Bull. 378*, Bureau of Mines, 1934.
[4] Grumell, E. S., and Dunningham, A. C., "Combustion of Fuel on a Traveling Grate," *Jour. Inst. Fuel*, vol. 12, No. 62, 1938, p. 87.
[5] Dunningham, A. C., "Fuel Bed Temperatures," *Jour. Inst. Fuel*, vol. 23, No. 133, 1950, p. 242.
[6] Marksell, W. G., et al., "Mode of Combustion of Coal on a Chain Grate Stoker," *Fuel in Science and Practice*, vol. 25, No. 1, 1946, p. 4; No. 2, p. 30; No. 3, p. 78; No. 4, p. 109; No. 6, p. 159.
[7] Dunningham, A. C., and Grumell, E. S., "Factors Affecting the Temperature of Traveling-Grate Stokers," *Fuel in Science and Practice*, vol. 17, 1938, p. 327.
[8] Carman, E. P., and Reid, W. T., "Ignition Through Fuel Beds on Traveling- or Chain-Grate Stokers," *Transactions*, ASME, vol. 67, 1945, p. 425.

TABLE I—PHYSICAL PROPERTIES AND PROXIMATE ANALYSES OF FUELS TESTED

Type of Fuel	High-temperature Coke	Anthracite	High-volatile A Coal	Sub-bituminous B Coal
Size range, inches	$^{1}/_{2} \times ^{1}/_{4}$	$^{9}/_{16} \times ^{5}/_{16}$	$^{5}/_{8} \times ^{5}/_{16}$	$^{5}/_{8} \times ^{5}/_{16}$
Bulk density, lb/cu ft	27	50	40	40
Void volume, per cent	52	40	49	48
Proximate analysis, as received, per cent:				
Moisture	2.1	2.0	1.6	21.6
Volatile matter	1.0	6.1	37.2	30.6
Fixed carbon	86.2	82.4	55.8	43.4
Ash	10.7	9.5	5.4	4.4
Ash-softening temperature, °F, approximate	2350	2700	2600	2300

maintain the same air rate. The slope of the ignition plane, *A-C*, becomes progressively greater until *C* has reached *B*; at this point the entire bed will have been ignited. There will then be a vertical plane, *A-B*, bounding the raw and the ignited fuel.

Evidently for some relatively low grate speed and for some given primary air rate the ignition plane *A-B* would remain vertical and stationary. In this state of equilibrium the grate speed, r_g, would equal the horizontal rate of ignition travel, r_h.

Owing to the experimental difficulties of measuring r_h in terms of r_g, experiments were conducted in a stationary bed in a manner that permitted direct measurement of r_h. The objective of this work, which is reported here, was to evaluate the behavior of four coals of different rank under conditions of ideal crossfeed ignition and therefore to complement previous studies of the other two modes of combustion, overfeed and underfeed.

It should be noted that this investigation was concerned only with the rate of travel of the ignition plane, and no effort was made to determine the weight of combustible consumed during the ignition period.

Acknowledgments

The authors are indebted to J. J. Pfeiffer, chemical engineer, Combustion Research Section, for assistance in conducting the tests.

Apparatus

Fig. 2 shows the arrangement of the test furnace. The fuel bed measured 6.5 in. thick in the direction of air flow, 12.75 in. high and 19 in. wide. The air flow was directed horizontally from the plenum chamber through the front grate and the bed. Any unreacted air, the volatile matter and combustion products generated in the bed passed through the water-cooled grate upward to the exhaust hood. A portion of the fuel bed could be observed at all times through the spaces between the bars of the water-cooled grate. The relative opacity of the products of combustion, condensation on the grate bars, and the progress of combustion thus observed were important in interpreting the test data.

A refractory-lined stack hood supported on a corner post resting on a hydraulic jack could be raised and moved aside to give access to the fuel bed.

The desired air rates were maintained automatically by a regulating valve, operated by a mechanism under the control of the pressure differential across the measuring orifice, as illustrated and described in a previous investigation.[8]

The ignition temperatures in the bed were determined by 28-gauge chromel-alumel thermocouples inserted through the firebrick bottom of the furnace. All of the ten couples were placed in the vertical middle plane of the bed, Fig. 2. One set of four couples was located in a line approximately one inch from the water-cooled grate, another set of four in a line about one inch from the rear grate, and the other two in a line down the center of the bed.

Experimental Procedure

For exploratory tests with coke, the fuel bed was used without the refractory hopper in Fig. 2. The top layer was ignited by a Glo-bar heated hood, brought up to a predetermined temperature before the test and moved onto the furnace for initial ignition. After establishing ignition to a depth of about $^{1}/_{2}$- to $^{3}/_{4}$-in., (indicated by the upper row of couples) the Glo-bar hood was moved aside to its original position, the top of the bed covered with a preheated plate of firebrick, the edges sealed with mortar, the exhaust hood transferred to the test furnace, and the blower started.

Temperature rise of the thermocouples in the respective levels was recorded up to temperatures at which the couples were destroyed, or at least up to 2000 F, depending on operating conditions. A 1000 F isotherm plane in the fuel bed was chosen arbitrarily as the ignition plane for all tests. No serious error would occur if a temperature between 600 and 1200 F were chosen since the rate of temperature rise in this range is very steep. While it would have been desirable to secure frequent gas samples during each test to compute burning rates, it is evident that the primary air passes through both green fuel and ignited fuel, the ratio of these varying with time, and gas samples would not represent combustible burned.

When air rates over 400 lb/sq ft/hr were used, consumption of the fuel in the combustion zone became so rapid that maldistribution of the air developed as a result of empty spaces created in the top of the bed. Consequently we devised a new technique for igniting and maintaining the bed depth. The furnace was provided with the firebrick hopper, Fig. 2, having a fuel capacity of 80 per cent of that of the bed proper. Initial ignition was then accomplished by spreading a layer of incandescent (about 2000 F) coke on top of the bed. This coke was prepared in a small glass-heated furnace. This hopper then was filled quickly with crushed refractory, which was of the same size consist as the fuel. Finally, the cover plate was sealed quickly in place and the test started. This procedure proved satisfactory with all of the fuels tested.

The fuels used in the study included one high-temperature coke, an anthracite, a high-volatile "A" coal, and a subbituminous "B" coal, Table I.

Results

One of the first observations made was determination of the slope of the ignition plane at any given time, as indicated by the thermocouples in the bed. With high-temperature coke and an air rate of 50 lb/sq ft/hr the plane sloped as shown in Fig. 3. The slope became steeper as the air rate decreased but became level between air rates of 100 and 1000 lb/sq ft/hr, as exemplified in Fig. 3 for an air rate of 340 lb/sq ft/hr. With anthracite, the ignition plane was sloped up to an air rate of about 200 lb/sq ft/hr and level above this value. Tests

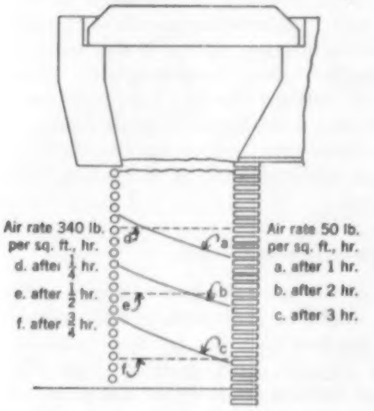

Fig. 3—Ignition plane shifts as air rates are changed. Solid lines show shift for 50 lb, dotted for 340 lb air rates through bed

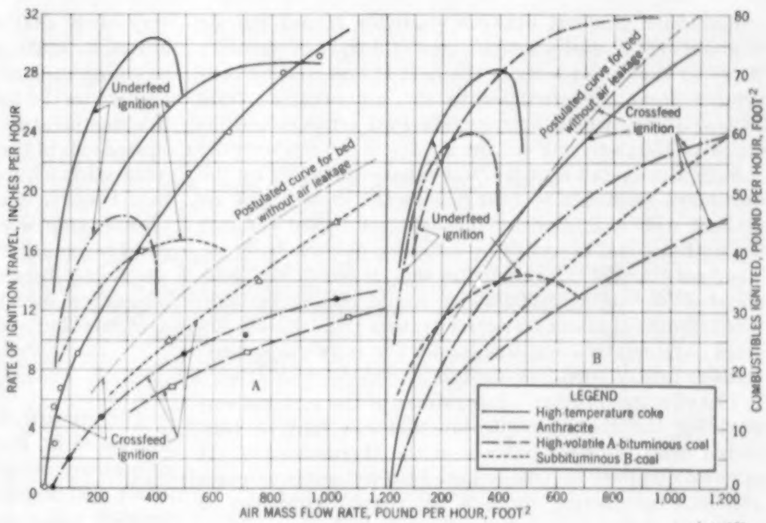

Fig. 4—Chart A, left, pictures the travel of the ignition plane in inches per hour for both pure crossfeed ignition and underfeed. Chart B, right, relates this travel to quantity of combustible ignited based on Chart A, the density of fuel bed, and its combustible content

with high-volatile "A" and subbituminous "B" were made only above an air rate of 400 lb/sq ft/hr, and the ignition plane was found to be horizontal in each test and at any given time in each test.

This horizontal ignition plane was similar to that found in previous investigations of pure underfeed ignition.[8] In both cases the plane traveled downward while remaining substantially horizontal. Since air flow and ignition travel were at right angles in these studies as contrasted to their opposed directions in underfeed ignition this observation is most interesting.

The rates of ignition travel (in inches per hour) and the rate of ignition (in quantity of combustible ignited, lb/sq ft/hr), for the four fuels tested, as determined from the propagation rate of the 1000 F isotherms in the bed, are plotted against the air mass velocity in Fig. 4. This figure also shows, for comparison, the ignition rates of these same fuels under conditions of pure underfeed burning.

The travel of ignition in inches per hour, Chart A, Fig. 4, was determined by the propagation rate of the 1000 F isotherm. The rate of ignition in quantity of combustible ignited, lb/sq ft/hr, Chart B, Fig. 4, was determined from the data of Chart A, the bulk density of the green fuel bed and its combustible content, Table I.

Discussion of Results

In the usually accepted sense of reactivity of solid fuels, the relative reactivity of the fuels tested would be, in descending order, as follows: subbituminous B, high-volatile A, anthracite, and high-temperature coke. However, these tests revealed this order to be completely reversed. The same phenomenon has been noted under certain conditions in connection with underfeed ignition tests. Since these results are best explained on the basis of heat transfer, the role of heat transfer, as it affects the rate and the relative direction of the plane of ignition, will be briefly discussed.

Role of Heat Transfer

It is simplest first to consider an underfeed fuel bed. Heat is transferred by three modes: (*a*) radiation both from the surface of the hotter particles and the surrounding luminous flame and nonluminous gases, (*b*) convection between the gases and the particles, and (*c*) conduction within individual particles and between contiguous particles.

Fig. 5 illustrates the importance of surface radiation as the primary mode of heat transfer in the ignition zone. The location of the thermocouple between an ignited particle A and an unignited particle B is shown and it is assumed that the thermocouple indicates the arbitrary ignition temperature of 1000 F.

The heat conducted downward through a layer of, for example, low-temperature coke of an average particle diameter of 0.25 in. with an assumed k value of 0.1 Btu/hr/ft/deg F, and an assumed temperature gradient of 1500 F, is about 2000 Btu/sq ft/hr. To simplify calculation, the layer of cold particles B was assumed to be replaced by a perforated $^1/_4$-in. plate of coke having 30 per cent open area.

The heat that could be transferred by convection from the layer of $^1/_4$-in. particles to air of ambient temperature passing upward can be estimated by using the conventional formula for heat transfer between air and spheres

$$\frac{h_c D_p}{k_f} = 0.33 \left(\frac{D_p G}{\mu_f}\right)^{0.6} \qquad (1)$$

where

h_c = heat transfer coefficient
D_p = particle diameter
G = mass velocity of air
k_f = heat conductivity of air film
μ_f = absolute viscosity of air at film temperature

Thus, for an average particle diameter of 0.02 ft (0.25 in.), an air-film temperature of about 100 F, and air mass flow of 200 lb/sq ft/hr, an h_c value of about 4 Btu/sq ft/hr/deg F is obtained. For an assumed average

temperature gradient between particles B and the air of about 600 F, and a surface area of 3 sq ft of particles B per sq ft of cross-section, the heat transferred by convection from the particles to the air becomes 7000 Btu/sq ft/hr, which corresponds to a temperature increase of 150 degrees F for the air.

Since the overall heat-transfer rate is controlled by the maximum resistance to heat flow in the system, the air preheat will be limited by the heat conducted through the particles and absorbed by radiation at their surfaces. The heat transfer by conduction was shown earlier to be about 2000 Btu/sq ft/hr, which would give a temperature increase of about 50 degrees rather than the 150 degrees obtained by considering only the convection heat-transfer rate of 7000 Btu/sq ft/hr.

The effective radiant temperatures of the surfaces surrounding the thermocouple junction can now be estimated from the heat balance of the thermocouple. It may be assumed that heat losses by radiation to gases and heat conduction through the couple wires can be neglected. The heat lost by the couple by convection to the air then equals the heat received by radiation from the radiant surfaces.

$$h_c\ (t_c - 120) = \epsilon_r\ h_r\ (t_R - t_c) \tag{2}$$

where

- t_c = the unknown couple temperature
- 120 = air temperature at thermocouple, deg. F
- t_R = the effective radiant surface temperature
- h_c = heat transfer coefficient for couple wire and junction
- h_r = heat transfer coefficient for surface radiation
- ϵ_r = emissivity factor for radiation of couple, assumed 0.80

h_c can be calculated from the formula for forced convection to wires:

$$\frac{h_c D_0}{k_f} = 0.32 + 0.43 \left(\frac{D_0 G}{\mu_f}\right)^{0.52} \tag{3}$$

and the following data:

- D_0 = 0.002 ft (22 gage wire)
- k_f (for 100 F, approximate average air film temperature) = 0.015 Btu/hr/ft/deg F
- G = 200 lb/sq ft/hr
- μ_f = 0.045 lb/ft/hr

When the above figures are used in equation (3) h_c is obtained as 24 Btu/sq ft/hr/deg F.

Substituting this value and the original assumed value of 1000 F for the thermocouple temperature in the radiant-heat-balance equation, (2), gives an equation with two unknowns, h_r and t_R. The term h_r can be represented approximately as a function of t_R. Simultaneous solution of the two functions by trial and error gives a value of 42 for h_r and 1700 for t_R. This latter value is the mean temperature of the surfaces surrounding the thermocouple.

The heat flow by radiation between the surfaces depends on the temperature difference. If this difference is successively assumed to be 200, 400 and 600 degrees F, with a mean temperature of 1700 F, the heat flow from particle A to particle B under black-body conditions is 14,000, 28,000 and 42,000 Btu/sq ft/hr, respectively. The h_r value is essentially constant at about 70 Btu/sq ft/hr/deg F for these conditions.

This example indicates that radiant-heat transfer is the major factor in raising the surface temperature of the colder particles B to the ignition temperature. Because of the poor thermal conductivity of coal it is probably very likely that the bottom surfaces of the particles are heated by multiple reradiation from surfaces below voids receiving radiant heat through the voids. The formula also shows the influence of air rate on the indicated ignition temperature as being roughly of the order of the square root of the air rate. If, however, clouds of opaque material, such as volatile matter, fill the voids, radiant heat transfer is markedly reduced by absorption. This phenomenon would account for the fact that high-temperature coke, which had a negligible volatile content, was found to be more responsive with respect to the rate of ignition travel than subbituminous B coal which had a high volatile content.

Slope of Ignition Plane

The upward slope of the ignition plane obtained with low air rates, Fig. 3, might be explained, in the absence of measurements of gas-flow patterns, by the combined effect of decreasing oxygen concentration along the ignition plane and the natural tendency of hot gases to rise rather than to proceed straight across the bed. This explanation suggests that at low air rates the gas flow across the bed is more nearly streamline than turbulent, as regards overall effect. The ignition planes become more nearly horizontal with increasing air rates. Apparently greater velocity of air through the voids results in more turbulent flow and in a more nearly horizontal flow of the hot gases and the air.

Oxygen appears to be supplied to the ignition plane exclusively from below the plane, except for a very narrow zone along the air-inlet grate. Expressed in average particle sizes, the coke bed was about 15 particles thick in the direction of air flow. The beds with other fuels ranged from 20 to 25 particles. When ash distribution in the bed was studied, after cooling of the bed in the apparatus, which was kept tightly closed, it was evident that oxygen must have been consumed within about one inch from the grate, corresponding to a width of about three to four particles.

Ignition Rates in Relation to Reactivity of Fuels

The ignition rates in the fuel beds tested, Fig. 4, decreased in the following order: high-temperature coke, subbituminous B coal, anthracite, and high-volatile bituminous A coal, as originally determined.

In comparing the ignition rates obtained here with those obtained previously in pure underfeed ignition, distinction will be made between the results of the three free-burning fuels, namely, high-temperature coke, anthracite, and subbituminous B coal, and the non-free-burning coal, high-volatile A bituminous coal. The crossfeed ignition rates obtained for the latter coal, as given in Fig. 4, are believed to be too low due to bypassing of air, and that probably about 80 per cent higher rates could be obtained if the testing procedure were modified to prevent such bypassing. An adjusted postulated value for the rate of ignition travel and for the rate of ignition shows on Fig. 4 as a light line. This line is suggested as a guide to what might be expected with a moving bed where bypassing of air could be avoided.

For primary air rates up to about 500 lb/sq ft/hr the measured crossfeed ignition rates of the three free-burning fuels are about 40 to 60 per cent, or roughly one-half,

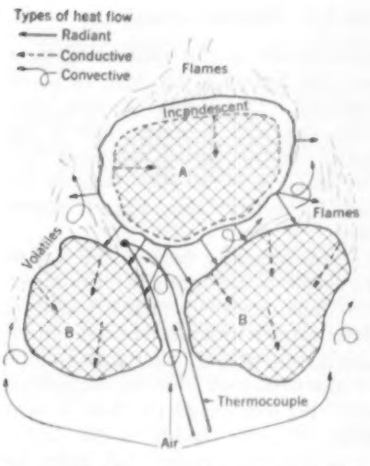

Fig. 5—Schematic view, above, pictures how the three heat-transfer methods work between particles

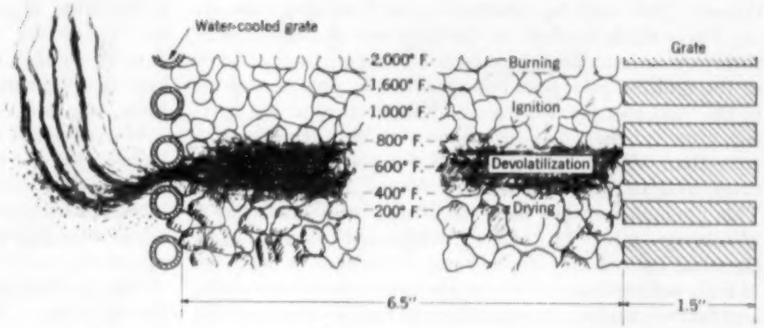

Fig. 6—Temperature gradient and zones of drying, devolatilization, ignition and burning show for a bed of subbituminous coal. The clouds of evolved volatiles limit the amount of radiant heat transfer, Fig. 5

those obtained in pure underfeed ignition. The same figure would hold also for the high-volatile A coal if its ignition travel is adjusted as noted above. This phenomenon may be due to the air flowing turbulently along the ignition plane, where products of combustion and of devolatilization will dilute the air, thus tending to reduce temperatures in the ignition zone. In addition, these products may also interfere with heat transfer by radiation in this zone. This is not possible in pure underfeed ignition.

Generally, it can be stated that with crossfeed ignition and with the bed restricted between two grates, rates of ignition equal to or exceeding the maximums obtained with pure underfeed ignition can be reached if the air rates are increased sufficiently. For example, high-temperature coke, which has a maximum rate of ignition underfeed of 71 lb/sq ft/hr at a 400-lb primary air rate, will have the same rate of ignition at a 1000-lb primary air rate under crossfeed conditions. Indications are that the ignition rates for pure crossfeed ignition will increase further as the air rate is increased beyond the maximum air rate available for use in these tests.

The lowest temperature at which a small particle of solid fuel ignites often is used as a relative measure of its reactivity. Referring to Table II, this ignition temperature is given approximately for the kinds of coal that were used in these tests. It will be noted that high-temperature coke had the highest ignition temperature, 1200 F, and therefore the lowest reactivity, and subbituminous B had the lowest ignition temperature, 400 F, and therefore the highest reactivity. However, the rate of ignition in underfeed or in crossfeed combustion would be a more rational index of the reactivity of the fuel, since the rate of ignition reflects the amount of fuel consumed.

The maximum ignition rates for both modes of combustion also are given in Table II. It is evident that the relative reactivities on this basis are completely reversed with respect to the high-temperature coke and subbituminous B. The relation between anthracite and high-volatile A bituminous and the subbituminous B coals shows less discrepancy from the conventional reactivity concept, but the reactivities and ignition rates still deviate rather widely. Previous analysis of the effects of various modes of heat transfer between particles in the ignition zone and the following analyses may help to explain these discrepancies and differences between conventional reactivity data and observed burning rates in fuel beds.

Fig. 6 illustrates schematically the temperature gradient and the relative locations of the zones of drying, devolatilization, ignition, and burning in a bed of subbituminous B coal. The clouds of volatiles evolved below the ignition zone will limit the amount of radiant heat transfer between ignited and unignited fuel particles, and therefore the rate of travel of the ignition plane will be retarded as compared to a fuel with a very low volatile content. Moreover, latent heat of vaporization of the moisture in the coal will absorb additional heat. These same phenomena in differing degree may be expected to occur with high-volatile A coal and any other fuel with appreciable volatile content. Fig. 5 illustrates how heat transfer works in a fuel bed.

TABLE II—RELATIVE RATES OF IGNITION AND "REACTIVITY"

	H.T. Coke	Anthracite	H.V. A	Subb. B
1. Conventional concept of reactivity				
(a) Qualitative statement	Lowest			Highest
(b) Approx. ignition temperatures, °F obtainable in laboratory tests	1200	1000	700	400
2. Pure underfeed ignition				
(a) Max. ignition travel, in./hr, at optimum air rates	30.5	18.3	28.5	16.6
(b) Optimum air rates, lb/sq ft/hr	400	275	900	500
(c) Ratio of max. ignition travel of fuels to that of coke	1.00	0.60	0.94	0.55
(d) Max. ignition rates in pound of combustibles/sq ft/hr at optimum air rates	71.0	59.5	79.5	36.2
(e) Ratio of max. ignition rates of fuels to that of coke	1.00	0.84	1.12	0.51
3. Pure crossfeed ignition				
(a) Ignition travel, in./hr, at highest available air rate of 1200 lb/sq ft/hr	32.5	13.4	22.5*	20
(b) Ratio of ignition travel of fuels to that of coke	1.00	0.41	0.69	0.62
(c) Ignition rates in pound of combustibles/sq ft/hr at 1200 lb air/sq ft/hr	77.0	59.0	84.0*	59.0
(d) Ratio of ignition rates of fuels to that of coke	1.00	0.77	1.09	0.77

* Adjusted for air bypassing the bed.

High-Temperature Coke

Referring now to the high-temperature coke, the most striking fact is that it had the highest experimentally determined crossfeed rate of ignition of any of the fuels tested. This may be ascribed to the following factors: (*a*) The volatile content of the coke was negligible, and therefore radiant heat transferred between the particles in the ignition zone was not absorbed by opaque vapors in the void spaces; and (*b*) the temperature in the ignition zone is believed to be higher with high-temperature coke than with bituminous coals, for given sizes and air rates, at least up to air rates of 400 to 500 lb/sq ft/hr. This phenomenon has been confirmed by Nicholls[2] at a 350-lb air rate. Of course, additional physical and chemical factors may explain the differences in behavior of high-temperature coke and low-rank bituminous coals, and further studies of combustion in fuel beds are needed to obtain a complete picture of the complex heat- and mass-transfer processes in such beds.

Anthracite

The reasons given for high rates of ignition observed in pure crossfeed beds of coke would also appear to apply to beds of anthracite, yet ignition rates for anthracite are about half those for coke in inches per hour and about three-quarters in pounds of combustible.

The most reasonable explanation for this appears to lie in the relatively large difference in thermal diffusivity of the two fuels. Thermal diffusivity is the thermal conductivity divided by the product of the density and the specific heat of a solid. Since the bulk density of anthracite is roughly twice that of high-temperature coke, the thermal conductivity of the anthracite is roughly one-third that of the coke, and since the specific heat of these materials is about the same, the thermal diffusivity of the coke would be about six times that of the anthracite. Accordingly, the rate of ignition, for a given amount of radiation, would be less for the anthracite than for the coke in proportion as the ignition rate is affected by the thermal diffusivity of the two fuels. Since, however, thermal diffusivity is concerned with conduction of heat within the particles and, as has previously been shown, radiation is the major factor in establishing rates of ignition, the effect of differences in thermal diffusivity will be much smaller than the six-to-one ratio mentioned above.

The large effect of differences in bulk density is shown by the relative position of the curves for coke and anthracite in Charts A and B, Fig. 4. Note how much closer the curves are in chart B where compensation has been made for differences in bulk density.

Another difference between these fuels that might have appreciable effect on relative rates of ignition of coke and anthracite concerns the shape of the pieces. Anthracite pieces tend to be flatter and more rectangular in cross-section than the pieces of coke which have a greater sphericity. Accordingly, the pieces may lay in such a way that radiation through the voids may be reduced materially. This would give greater effect to the above described factor of thermal diffusivity. Investigation of the basic reasons for these differences would be of interest, but lack of facilities and time prevented such a study in connection with these tests. Once again more study seems in order.

High-Volatile A Bituminous Coal

The rates of ignition travel in this coal using pure crossfeed ignition were the lowest of the four fuels, as experimentally determined. There was obvious maldistribution of air with this coal, however, and if the test values are adjusted for this, using the underfeed data as a guide, the adjusted rates fall close to those for high-temperature coke. The light line, Fig. 4, shows these adjusted values.

If it were not for certain retarding factors, the rate of ignition for the high-volatile A coal probably would exceed that for the high-temperature coke in crossfeed beds, as was the case at high air rates in underfeed beds. One of these retarding factors is undoubtedly the large volume of volatile matter and soot driven off from the coal ahead of the ignition plane. This will retard the flow of heat by radiation. Another retarding factor is the latent heat of vaporization of volatile matter that must be supplied from the heat source before ignition of the fuel. A third retarding factor may be the effect of the plastic layer itself which not only reduces diffusion of air to the ignition zone but, probably more important, results in substantial reduction of void space with consequent reduction in radiant surfaces and in passages for transfer of heat by radiation.

Overcoming the above retarding factors in a fixed-bed test apparatus as used in this investigation would be difficult. It would involve the use of a moving shield or plenum to force air through the igniting and burning zones. In a proposed commercial furnace, with a bed moving downwardly between the restraining grates, such difficulty need not be encountered, as a plenum could be used on the air supply side to provide an air blast just as the ignition-burning zone passed the plenum. As contrasted to the fixed-bed test apparatus, the proposed commercial moving-bed furnace could provide proper air distribution to the ignition and burning zones, and under these conditions rates of ignition of the order of magnitude of the adjusted light line on Fig. 4 are believed possible.

Subbituminous B Coal

The reactivity of the subbituminous coal was the highest of the four fuels tested, by conventional reactivity-determining methods as previously noted. However, in both the underfeed and the crossfeed tests this coal gave the lowest rates of ignition of these four fuels. This may be explained, at least partly, by examining the characteristics of the coal and the respective test conditions. With underfeed ignition, the relatively high natural bed moisture of the subbituminous coal must be evaporated before the coal is ignited. This moisture first retards ignition by taking up its latent heat of vaporization, and then, when it reaches the hot burning zone of the bed, it is involved to some extent in the heat-consuming water gas reaction. Also in underfeed ignition and burning of subbituminous coal there is a relatively thin layer of burning fuel at all practical air rates, and the heat content of the bed, including that available to force the ignition plane down into the green fuel, is materially affected by radiation losses from the top of the bed.

With pure crossfeed ignition, the moisture in the coal is heated and vaporized in the ignition plane and travels across the bed under, rather than through, the ignition

plane and, mixed with primary air, volatile matter, and combustion products, leaves the bed beneath the ignition plane.

The high reactivity of the subbituminous coal is effective in giving a relatively high rate of pure crossfeed-ignition travel despite the shielding effects of the vapors and gases and the heat-of-vaporization requirements.

Conclusions

1. Pure crossfeed ignition does not occur in actual operation in fuel beds on traveling grates, where ignition is of the underfeed principle under virtually all operating conditions. Only under the extreme conditions of very low rate of grate travel and very high air rates can attainment of pure crossfeed ignition be visualized.

2. The rates of ignition in pure crossfeed beds at comparable primary air rates with pure underfeed ignition are much smaller than the underfeed ignition rates.

With confined fuel beds, however, as with the test bed used, and above the range of air rates that give stable beds on traveling-grate stokers, all the four fuels tested showed an increase in their rates of ignition with increase of air rate, and no maximum ignition rates were obtained up to air rates of 1200 lb/sq ft/hr. The slopes of the ignition curves definitely suggest that even higher crossfeed ignition rates could be expected with still higher air rates. Two fuels, coke and subbituminous coal, gave maximum crossfeed rates that were measurably higher than those obtained with underfeed ignition within the range of air rates used. When the rates of ignition for high-volatile A bituminous coal were adjusted for maldistribution of air, the rates for this coal also were higher with crossfeed ignition at high air rates.

3. Evolution of tars, vapors and soot masks the radiation effect in the ignition zone with some fuels, and development of a plastic layer with coking coals explains, at least in part, the low rates of ignition of such highly reactive coals as subbituminous B and high-volatile A coals as compared to high-temperature coke of comparatively low reactivity. Two other possible retarding effects are also discussed.

4. Chemical reactivity in its conventional concept apparently bears no relation to the rates of ignition, this conclusion applying to both underfeed and pure crossfeed ignition. The behavior of the two fuels with extreme properties—high-temperature coke, and subbituminous B coal—indicates that the reactivity as measured by the rates of ignition in the bed is affected significantly by the mode of heat transfer. This, in turn, is affected by such physical characteristics as the masking effect of volatiles and cooling effects of drying.

5. Up to the present time there have been no known applications of pure crossfeed ignition and burning in fuel beds, except for a small anthracite stoker. The present investigation, originally started because of scientific curiosity, has indicated that the pure crossfeed principle could be applied in commercial processes for special purposes. One of these possibilities is the combustion of low-grade fuels such as washery refuse.

Practical Aspects

From the basic considerations discussed in connection with the diagram of a traveling-stoker bed, Fig. 1, it follows that pure crossfeed burning will be approached in this type of bed if the ignition rate can be materially increased in relation to the rate of travel of the grate. Although one method of accomplishing this would be to increase air rates, the extent of such increase is limited without exceeding the point of bed stability in the traveling-grate stoker. However, if the bed were restrained, as was the case in these tests, very high rates of crossfeed ignition might be attained, at air rates higher than the maximum rate possible in pure underfeed beds. The difference in behavior would be expected to be most pronounced with high-temperature coke and the highest ranks of bituminous coals, i.e., low-, medium-, and high-volatile A bituminous coals.

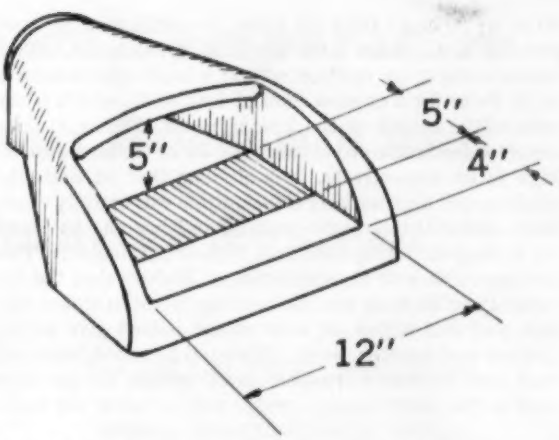

Fig. 7—Special retort, the Risdon, accomplishes pure crossfeed ignition for anthracite at published rates of air supply of 740 to 800 lb per sq ft per hr and fan limitations were the limiting factor in stoker ouput

Another method of increasing ignition rate in relation to the grate speed on traveling-grate stokers is to reduce the rate of grate travel to the extent that it approaches the rate of crossfeed ignition, which would give essentially crossfeed ignition on a traveling grate. This is accomplished when a traveling-grate fire is banked, so there is little or no grate movement and a very low air rate. This is also accomplished in a certain type of anthracite stoker such as the Risdon retort, Fig. 7, taken from a report of tests on this type stoker by P. A. Mulcey.[9]

While basically this stoker is like a traveling-grate stoker, except that the fuel moves instead of the grate, the stoker operates essentially crossfeed because the fuel is fed only as fast as it ignites in the crossfeed manner. The slotted grate area is 0.42 sq ft, and the total area, including the "spillover" plate at the rear, is 0.75 sq ft. The feed rates used by Mulcey for medium and high burning rates were 14.3 and 18.4 lb per hr, respectively, of dry rice anthracite. Calculating the air rates from the data given in Mulcey's report, using reasonable assumptions as to ash content and coal density, it is indicated that air rates were approximately of the order of 740 to 800 lb/sq ft/hr for the actual slotted grate area of 0.42 sq ft. In Fig. 4, the pure crossfeed ignition rate is about

[9] Mulcey, P. A., "New Developments in Anthracite Stoker Retorts," *Transactions*, 7th Annual Anthracite Conference, Lehigh University, Bethlehem, Pa., 1949, p. 225. "Commercial Crossfeed Stokers," *Transactions*, 9th Annual Anthracite Conference, Lehigh University, Bethlehem, Pa., 1951, p. 97.

50 lb/sq ft/hr at these air rates, for anthracite of comparable size consist and chemical composition. This corresponds to an ignition rate in a horizontal direction of 21 lb/hr for a cross-section of 0.42 sq ft, which is the area of the mouth of the Risdon retort. Since Mulcey reported feed rates of 14.3 and 18.4 lb/hr for medium and high rates, respectively, it is obvious that at both the medium and high burning rate, ignition was entirely crossfeed, and that the rate of ignition and burning as found by Mulcey do not represent the highest obtainable. This is compatible with the suggestion of Mulcey that the fan capacity in his tests was the limiting factor in stoker output, and that higher air rates would indeed give higher ignition and burning rates. It should be noted, however, that such increased *crossfeed* rates, within the air rates used in this investigation, would still be below the maximum underfeed ignition rates shown in Fig. 4. This shows that while the maximum ignition rates of pure underfeed burning are not utilized in the type stoker in Fig. 7, that the air rate that can be applied is about two times the air rate that could be used in pure underfeed ignition to obtain maximum rates of ignition.

A practical application of the pure crossfeed ignition principle can be visualized if, referring to Fig. 2, the fuel would be allowed to move downward by gravity. One advantage over the principle of the Risdon retort would be that no power would be necessary to move the fuel. Very high rates of primary air could be visualized for this restricted bed. To obtain more insight into the advantages and disadvantages of this principle, more basic study seems desirable.

Flyash Abatement On An Electric Company System

Costs involved in correcting the flyash discharge problems of older, established power plants as well as designing and selecting equipment for this duty on new power plants are frequently presented as a lump sum charge. The average engineer, let alone the average citizen, finds these figures so large that their significance is not fully appreciated.

A paper presented about a year ago[1] discussed these costs and broke them down to a unit figure. The author outlined the air pollution control problem confronting his company by describing the company's system as one that burns about 3,400,000 tons of coal per year and has a total capacity of roughly 2,000,000 kw comprised of older stoker fired boilers as well as modern large steam generating units burning pulverized coal.

With an experience record reaching back to 1935 on dust collectors for pulverized coal installations the company has been through all the development phases. This experience embraces mechanical as well as electrostatic dust collectors, both separately installed and in combination. It further has kept up with the latest requirements in eliminating the occasional stack puffs produced by intermittent rapping in the cleaning of the electrostatic dust collectors.

When collectors were selected for the new Delaware Station placed in operation during 1953 with two 875,000 pounds per hour pressurized boilers, combination collectors were selected.

A mechanical collector was located between the air heater stages in the 400 F zone and the electrical precipitator in the 250 F zone in an attempt to improve removal of fly ash and retain surface cleanliness when operating with low exit gas temperatures.

A separate conveyor system of the continuous type for both the mechanical collector and the electrical precipitator was installed and was intended to improve removal of collected material.

At Delaware Station combination collectors with their associated conveyors account for an approximate expenditure of $2.50 per kw of turbine-generator nameplate capacity. Building costs and storage facilities are not included in this amount. Operating and maintenance costs are additional items.

At Cromby Station where a 1,050,000 pounds per hour and a 1,450,000 pounds per hour pulverized fuel fired boiler will go into operation in 1954 and 1955, respectively, an overall efficiency of $98^1/_2$ per cent with combination collectors is anticipated.

It is expected that the Cromby installation of combination collectors and associated conveyors will show an expenditure of approximately $3.25 per kw of turbine-generator nameplate capacity, the increase reflects the higher collection efficiency in contrast to Delaware Station.

At Richmond Station where two electrical precipitators, installed in 1935 are operating, a mechanical collector in series with each electrical precipitator is expected to be installed. This additional capital expenditure of approximately $1.20 per kw of turbine-generator nameplate capacity installed will result in stack loadings approaching modern practice. A fortunate circumstance of space and existing structural steel makes this low unit cost possible. Increased low micron sizing to the electrical precipitator will require improvement to its vibrating system.

[1] "A Review of Flyash Abatement In An Electric Company System" by D. F. Schick, Jr., Philadelphia Electric Co. Presented before the East Central Section, Air Pollution Control Assn., Harrisburg, Penna., Sept. 24, 1953.

Selection of Optimum Temperature Conditions in Power Reactors and Their Heat Exchanger System†

These excerpts from a paper presented before the International Congress on Nuclear Engineering sponsored by the American Institute of Chemical Engineers at the University of Michigan last June provide techniques for evaluating optimum temperature conditions by the use of three parameters. Although primarily intended for liquid metal cooled reactors, the mathematical analysis is believed to be applicable to other types.

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OPTIMUM temperature conditions in a reactor power plant are considered to be those leading to the production of electric power by a base load plant at the lowest possible cost. Temperature conditions of primary concern will be the temperatures of the reactor coolant, temperature differences in the heat exchangers, and the pressure and temperature of the steam for the power cycle.

The selection of temperatures differing from the optimum values can increase the cost of power production appreciably. Consequently, considerable effort is justified to obtain temperatures which are most compatible with other reactor design conditions.

The cost of electric power consists of capital costs and operating costs. The capital cost in terms of mills per kwhr tends to be reduced by increasing the electrical output of a plant. Since the electrical output is the product of the reactor thermal power and the efficiency of power conversion, an increase in thermal power or efficiency tends to decrease the cost of power due to capital investment. The cost of electric power due to fuel replacement can be reduced appreciably by improving the efficiency but not by increasing the thermal power. Optimum temperature conditions will be those with the right balance of thermal power and efficiency to give the lowest sum of capital costs and operating costs. These optimum temperature conditions will be determined by the relative magnitude of investment and operating expenses.

The results of this investigation are expressed in terms of three parameters. λ_c describes the reactor coolant and fuel element; β is used to indicate the performance and cost of heat exchangers relative to other reactor investment; and the parameter Γ indicates the cost of fuel replacement relative to capital costs of the reactor.

Values of λ_c used in the calculations are of primary interest for liquid metal cooled reactors, but the method of analysis appears applicable to other types. The analysis is restricted to single flow, single cycle systems, so that split or zoned flow and the use of more than one steam cycle at a time are not subjects of investigation.

Heat Exchangers in Nuclear Power Plants

A. The Boiler

In this paper, the boiler is considered to consist of an economizer, an evaporator and a superheater. Each section of the boiler may be a separate heat exchanger, or the components may be combined. Shell and tube type heat exchangers have usually been considered for all but relatively small power plants. The tubes of these exchangers have been single-walled, double-walled with each pair of concentric tubes separated by a mercury annulus, or close fitting double-walled tubes with monitoring grooves cut on the outer surfaces of the inner tubes. The use of double-walled tubes reduces the possibility of accidental contact of the liquid metal and the water and permits the detection of leaks in the tubes which might lead to such an accident.

A heat exchanger using the double-walled tube with a mercury annulus is described by Brooks and Rosenblatt, and they give test results for the generation and superheating of 500 psia steam by hot NaK.[1*] The overall heat transfer coefficient of the evaporator varies between about 200 and 400 Btu/(hr)(sq ft)(deg F). The overall coefficient in the evaporator increases with increasing NaK Reynolds number, but the principal thermal resistance is in the walls of the tubes. The performance of the superheater depends largely on the Reynolds number of the steam, and overall heat transfer coefficients of about 150 to 200 were obtained at Reynolds numbers of about 6×10^4. These figures on the performance are presented to show a general magnitude.

A description and performance of evaporators using close fitting double-walled tubes with monitoring grooves

† Reprinted from Symposium Series, Vol. 50, No. 12, Part II, p. 181, by permission of the American Institute of Chemical Engineers.

* Numbers refer to bibliography at end of paper.

is given by King and Andrews.[3] Two different sizes of double-walled tubes were tested using NaK to evaporate water at pressures ranging from 113 to 1203 psia. The first double-walled tube with wall thicknesses of 0.065 in. had overall heat transfer coefficients of about 450 to 550 Btu/(hr)(sq ft)(deg F) for overall temperature differences between the NaK and water of about 500 to 760 deg F. The second double-walled tube with wall thicknesses of 0.049 in. gave overall heat transfer coefficients of about 650 to 800 Btu/(hr)(sq ft)(deg F) for temperature differences of about 370 to 600 deg F.

Comparative performance of a single-walled tube with a thickness of 0.065 inch is also given by King and Andrews.[3] Their tests showed overall heat transfer coefficients of about 1050 to 1300 Btu/(hr)(sq ft)(deg F) in evaporating water with NaK using temperature differences of about 180 to 360 deg F. The steam pressures used ranged from 113 to 1203 psia as for previous tests.

The data of King and Andrews show a decrease in the overall heat transfer coefficient with a decrease in the temperature drive. This is to be expected since the coefficient for nucleate boiling decreases with decreasing temperature drive.

B. The Intermediate Heat Exchanger

A violent reaction in the boiler between an alkali liquid metal and water would be serious, but such an explosion would be even more hazardous if the liquid metal were radioactive. To alleviate this danger, reactor designs with an alkali liquid metal as the primary coolant have a secondary coolant loop between the primary loop and the power plant working fluid. The heat is transferred from the primary to the secondary coolant in an intermediate heat exchanger.

Brooks and Rosenblatt describe the performance of two types of sodium to NaK heat exchangers which would be suitable for use as intermediate heat exchangers.[1] In both designs, the sodium and NaK are separately contained, and the space between the two containers is filled with stagnant sodium. Overall heat transfer coefficients of about 2000 Btu/(hr)(sq ft)(deg F) were obtained in their "flat tube" heat exchanger, while the coefficients in the "round tube," shell and tube type exchanger were about half as large.

No test data were available for single-walled liquid-metal to liquid-metal exchangers. Most of the thermal resistance is in the tube walls in the double-walled liquid-metal heat exchanger, so by using only one tube wall instead of two, considerable improvement in the performance might be expected.

C. Cost Estimates of Heat Exchangers

The costs of heat exchangers required for liquid-metal cooled nuclear power plants are not well known nor are estimates readily available. This lack of information is understandable. Accurate estimates are difficult to make because of the scarcity of experience with heat exchangers using liquid metal, and manufacturers are naturally reluctant to be quoted on prices which may be in error. Rough estimates of the cost of large heat exchangers of the types discussed previously may be made on the basis of cost information on more standard types of heat exchangers. The following estimates are very approximate and are intended solely to provide an order of magnitude to be used in subsequent calculations.

Aries and Newton estimate the installed cost of a stainless steel clad shell, stainless tube heat exchanger to be $17 per square foot for an exchanger with 5000 square feet of transfer area.[3] In terms of dollars per square foot, the cost decreases with size. A heat exchanger using liquid metal would probably require all welded joints, and exceptionally careful construction and checking to insure leak tightness. This might increase the cost of construction by around 50 per cent. On this basis, a single-walled tube heat exchanger suitable for use as an intermediate exchanger might be expected to cost in the neighborhood of $30 per square foot installed. About the same cost would apply to a boiler using single-walled tubes. Use of double-walled tubes tends to increase the cost of materials and construction. The cost of a double-walled tube type boiler is estimated to be approximately $50 per square foot of transfer area.

Analysis

A. General

The cost of electric power from a nuclear plant consists of capital costs, such as the investment in the reactor, liquid metal systems, heat exchangers, and power conversion equipment, and of operating expenses such as fuel replacement and general operation and maintenance. A mathematical expression for the cost of power will prove useful.*

$$\text{Power Cost}\left(\frac{\text{mills}}{\text{kwhr}}\right) = \frac{\text{Annual cost of reactor, cooling system, fuel investment and site}}{\text{Annual electric output}} + \frac{\text{Annual cost of heat exchanger}}{\text{Annual electric output}} + \frac{\text{Fuel replacement}}{\text{Efficiency}}$$
$$+ \text{Cost due to power conversion equipment} + \text{Operation and maintenance}$$

For convenience, this will be written symbolically

$$C_p = \frac{I_R r_R}{\eta q p} + \frac{I_E r_E}{\eta q p} + \frac{F}{\eta} + \frac{L r_L}{p} + C_{op} \qquad (1)$$

Suppose now that the reactor, cooling system (exclusive of heat exchangers and power conversion equipment), fuel inventory and the site are fixed. Although the coolant flow rate is fixed, the temperatures are not. Consequently, the variables will include the reactor power q, the efficiency η, and the cost of heat exchangers I_E. With these assumed conditions, I_R the investment cost of the reactor, cooling system, fuel inventory and site can be considered as constant. Within a sufficiently wide range, the cost of fuel replacement F can also be considered as constant. The cost of heat exchangers I_E will vary with the reactor thermal power, q, and with the temperature drives selected. Power conversion equipment costs, L, vary with the steam conditions and the variation has been the subject of separate studies. Some operation and maintenance costs will be the same every year regardless of operating temperatures, but others will vary, so it is difficult to predict how C_{op} will change as the operating conditions are altered. In summary, for the assumed conditions of a fixed reactor and coolant loop, the cost of electric power due to fixed investment, I_R, varies inversely as the electric output; the cost due

* For symbols and abbreviations, see Appendix B.

to fuel replacement, F, varies with the efficiency, η; and the costs due to power conversion equipment and operation and maintenance vary in other ways.

The cost of power can be reduced by increasing the efficiency, η, or the reactor thermal power, q, as is evident from expression (1). However, an inherent conflict exists between the two aims of maximizing the reactor thermal power and maximizing the efficiency of power conversion. If a maximum fuel element temperature limits the power, low coolant temperatures are desirable to increase the quantity of heat it is possible to generate in the reactor. On the other hand, high coolant temperatures are desirable to permit high steam pressures and temperatures with resulting high efficiencies. The optimum set of temperature conditions for a reactor will balance these conflicting aims to produce electric power at the lowest cost. The optimum conditions will be determined by the relative size of those cost factors which vary with the efficiency and those which vary with the electrical output of the plant.

An optimum boiler size will exist for any fixed reactor, coolant flow rate, and steam cycle. An increase in size of the boiler will permit an increase in the reactor thermal power, and this results in an increase in the cost of electricity due to the boiler and a decrease in cost due to the other investment items. The optimum size of boiler then is determined by the relative cost of the boiler and the other investment items.

In the subsequent analysis, optimum temperature conditions will be determined for particular reactors as a function of the relative cost of heat exchangers, investment costs, and fuel processing costs. The relative cost of heat exchangers and other investment costs are expressed in terms of a parameter β, the relative cost of fuel replacement in terms of Γ, and the reactor and cooling circuit performance in terms of a reactor parameter λ_c. The results do not include any variation in the cost of power conversion equipment such as the turbine, condenser or cooling water system, nor do the results consider a variation in the cost of operation and maintenance of the equipment.

B. The Parameter λ_c

The parameter λ_c is defined by the equation

$$\lambda_c = \frac{WC}{\alpha\, UA} = \frac{\text{Temperature drive between fuel and coolant in central fuel channel}}{\text{Temperature rise of coolant in central channel}}$$

If the properties of the coolant and fuel element are constant, a constant value of λ_c means a constant flow rate, W, for a particular fuel element and coolant channel. In the calculations, a particular power distribution is assumed for the reactor with the coolant so throttled in all coolant tubes that a maximum permissible temperature exists in one point of each fuel element. By these assumptions, the total coolant flow and reactor power are related to the power and flow in the central channel.

Calculation in terms of a constant value of λ_c has two principal advantages. First, a constant λ_c means a constant coolant flow rate for a particular reactor and this tends to fix the cost of the cooling circuit. Second, if the coolant flow rate is constant, the reactor power is directly proportional to $(t_f - t_1)$, the maximum fuel element temperature minus the coolant inlet temperature, as demonstrated in Appendix A.

Values of λ_c used in the calculations are based on results appearing in Reference 4. These results, for a particular reactor power distribution, indicate that maximum electric power is obtained at λ_c of about 3–4 if the maximum fuel element temperature is 1200 F. At larger values of λ_c, the electric power output and the efficiency decrease. Smaller values of λ_c give lower electric output but higher efficiency. At higher maximum fuel temperatures, the value of λ_c for maximum electric power increases.

C. The Heat Exchanger Parameters β and β_i

If a particular steam cycle, reactor and coolant flow rate are considered, the cost of power is approximately a function only of heat exchanger investment I_E, other investment described by I_R, and the reactor thermal power, q. With these conditions and relatively small variations in the reactor power, the cost of electricity due to fuel replacement, power conversion equipment and operation can be considered as constant. Equation (1) can be rewritten for these conditions as:

$$C_p - C_3 = \frac{I_R r_R}{\eta\, qp} + \frac{I_E r_E}{\eta\, qp} \qquad (2)$$

Successive steps will reduce this equation to one in terms of the maximum fuel element temperature, t_f, the coolant inlet temperature, t_1, and the parameters β and β_i.

The first term on the right side of (2) will be altered by substituting:

$$q = C_2\,(t_f - t_1)$$

As is shown in Appendix A, C_2 is a constant if attention is limited to a particular reactor and constant flow rate. Then

$$\frac{I_R r_R}{\eta\, qp} = \frac{I_R r_R}{\eta\, pC_2\,(t_f - t_1)} \qquad (3)$$

The second term on the right side of (2) includes the cost of the boiler and the intermediate heat exchanger. The total boiler area amounts to

$$A = \underset{\text{(economizer)}}{\frac{f_{ec}\, q}{U_{ec}\,\theta_{ec}}} + \underset{\text{(evaporator)}}{\frac{f_{ev}\, q}{U_{ev}\,\theta_{ev}}} + \underset{\text{(superheater)}}{\frac{f_{sh}\, q}{U_{sh}\,\theta_{sh}}} \qquad (4)$$

where f represents the fraction of total heat transferred in each boiler component, U is the overall heat transfer coefficient, and θ is the mean temperature difference. (The logarithmic mean is assumed to be the true temperature difference.)

To simplify the calculations, it was assumed that

$$U_{ec} = U_{ev} \qquad \text{and} \qquad 2U_{sh} = U_{ev} \qquad (5)$$

Then the expressions for boiler area (4) can be simplified to

$$A = \frac{q}{U_{ev}}\left(\frac{f_{ec}}{\theta_{ec}} + \frac{f_{ev}}{\theta_{ev}} + \frac{2f_{sh}}{\theta_{sh}}\right) \qquad (6)$$

For the conditions of a fixed steam cycle, reactor, and λ_c, the expression inside the parentheses of (6) can be shown to be a function only of the coolant inlet temperature, t_1, and will be called $\sigma\,(t_1)$.

$$\sigma\,(t_1) = \frac{f_{ec}}{\theta_{ec}} + \frac{f_{ev}}{\theta_{ev}} + \frac{2f_{sh}}{\theta_{sh}} \qquad (7)$$

If the cost of the boilers is C_1 dollars per square foot and

the amortization rate is r_b, the cost of electricity (mills per kwhr) due to the boiler is

$$\frac{C_1 A\, r_b}{\eta\, q p} = \frac{C_1\, r_b}{U_{ev}\, \eta p}\, \sigma\,(t_1)$$

Similarly, the cost of electricity due to the intermediate heat exchanger will be

$$\frac{C_4\, r_i}{U_i\, \eta_p}\left(\frac{1}{\theta_i}\right)$$

Since the cost of heat exchangers is considered to consist of the boiler plus the intermediate heat exchanger,

$$\frac{I_B r_B}{\eta\, q p} = \frac{C_1\, r_b}{U_{ev}\, \eta p}\, \sigma\,(t_1) + \frac{C_4\, r_i}{U_i\, \eta p}\left(\frac{1}{\theta_i}\right) \qquad (8)$$

Now the expression for the cost of power (2) can be rewritten by substituting (3) and (8) to give

$$C_p - C_2 = \frac{1}{\eta p}\left[\frac{I_R\, r_R}{C_2\,(t_f - t_1)} + \frac{C_1\, r_b}{U_{ev}}\, \sigma\,(t_1) + \frac{C_4 r_i}{U_i}\left(\frac{1}{\theta_i}\right)\right] \qquad (9)$$

The last step is to divide expression (9) by

$$\frac{1}{\eta_p}\,\frac{I_R r_R}{C_2}$$

and let

$$\left.\begin{aligned} B &= \frac{C_1 C_2 r_b}{U_{ev} I_R r_R} \\ \beta_i &= \frac{C_4 C_2 r_i}{U_i I_R r_R} \end{aligned}\right\} \qquad (10)$$

The resulting equation (11) is used in subsequent calculations to determine optimum temperature conditions for particular steam cycles, reactors, and values of λ_c, β and β_i.

$$\frac{\eta_p C_2}{I_R r_R}(C_p - C_2) = \frac{1}{t_f - t_1} + \beta\sigma\,(t_1) + \frac{\beta_i}{\theta_i} \qquad (11)$$

The parameter β is dimensionless and indicates the relative cost of the boilers to the investment in the reactor, cooling circuit, and fuel. A high cost, low performance boiler tends to increase β while an expensive reactor tends to decrease β. Use of the parameter β in reactor design requires some prior knowledge of costs and performance.

The parameter β_i is used for the intermediate heat exchanger and differs from β by the use of the appropriate heat transfer coefficients and costs.

D. The Fuel Replacement Cost Parameter Γ

The costs of electric power due to reactor, cooling system, heat exchanger, and fuel investment, and fuel replacement may be written by combining equations (1), (3) and (8).

$$C_p - \frac{L r_L}{p} - C_{op} = \frac{I_R r_R}{\eta p C_2 (t_f - t_1)} + \frac{C_1 r_b}{U_{ev} \eta_p}\, \sigma\,(t_1) + \frac{C_4 r_i}{U_i \eta p \theta_i} + \frac{F}{\eta}$$

Now divide this expression by $\dfrac{I_R r_R}{C_2\, p}$ and let

$$\beta = \frac{C_1 C_2 r_b}{U_{ev} I_R r_R}$$

$$\beta_i = \frac{C_4 C_2 r_i}{U_i I_R r_R}$$

$$\Gamma = \frac{C_2 F_p}{I_R r_R}$$

$$\frac{C_2 p}{I_R r_R}\left[C_p - \frac{L r_L}{p} \quad C_{op}\right] = \frac{1}{\eta}\left[\frac{1}{t_f - t_1} + \beta\sigma(t_1) + \frac{\beta_i}{\theta_i} + \Gamma\right] \qquad (13)$$

Equation (13) is used to determine the approximate optimum steam conditions for various values of the reactor parameter λ_c and heat exchanger parameters β and β_i.

The parameter Γ is an indication of the cost of fuel replacement relative to the investment in the reactor, coolant loop and fuel inventory. It is directly proportional to the constant C_2, the cost of fuel replacement and the plant capacity factor and inversely proportional to the annual cost of the reactor, coolant loop and fuel inventory.

Appendix A

Relation Between Reactor Power and Coolant Inlet Temperature

The power from the central coolant channel of a reactor where the axial power distribution is a chopped cosine function can be written as:

$$q_e = \alpha UA \frac{\sin\omega}{\omega}\sqrt{(t_f - t_1)\,(t_f - t_2) - \left(\frac{t_{2e} - t_1}{2\tan\omega}\right)^2} \qquad (A1)$$

where

$$\omega = \frac{\pi}{2}\left(\frac{L}{L_0}\right)$$

also

$$q_e = WC\,(t_{2e} - t_1) \qquad (A2)$$

Solve (A2) for t_{2e}, substitute in (1) to eliminate t_{2e}, square both sides of the resulting equation to remove the radical, and simplify the quadratic equation in q so obtained.

$$q_c^2\left[\frac{1}{\left(UA\dfrac{\sin\omega}{\omega}\right)^2} + \frac{1}{(2WC)^2}\right] + \frac{q\,(t_f - t_1)}{WC} - (t_f - t_1)^2 = 0$$

For a particular fuel element and coolant channel geometry and power distribution, U, A and ω will be constant and C can generally be assumed to be constant. If in addition, the coolant flow rate, W is constant, q_c^2 is a function if $(t_f - t_1)$. This can be written

$$Dq^2 + Eq_c\,(t_f - t_1) - (t_f - t_1)^2 = 0$$

and solved for q_c.

$$q_c = \frac{-E\,(t_f - t_1) \pm \sqrt{E^2\,(t_f - t_1)^2 + 4D\,(t_f - t_1)^2}}{2D} \qquad (A3)$$

(A3) can be simplified

$$q_c = (t_f - t_1)\left[\frac{-E \pm \sqrt{E^2 + 4D}}{2D}\right] \qquad (A4)$$

Equation (A4) shows that with a constant coolant flow rate, the power from the central channel is proportional to the difference between the maximum fuel element and the coolant inlet temperature. If the flux distribution in the reactor is fixed, the reactor power is proportional to the power in the central coolant channel. Consequently, under the assumed conditions, the reactor power is proportional to $(t_f - t_1)$.

Appendix B

Symbols and Abbreviations

A = Heat transfer area, sq ft
C = Specific heat, Btu/(lb)(deg F)
C_1 = Cost of boiler heat transfer area, \$/sq ft
C_2 = Constant relating reactor power to coolant temperatures for constant flow. $C_2 = \frac{q}{(t_f - t_1)}$, Btu/(hr)(deg F)
C_3 = $\frac{F}{\eta} + \frac{Lr_L}{p} + C_{op}$, mills/kwhr
C_4 = Cost of heat transfer area in intermediate exchanger, \$/sq ft
C_{op} = Cost of electricity due to normal operation and maintenance but not including fuel replacement, mills/kwhr
C_p = Total cost of electricity at the bus bars, mills/kwhr
D = Constant defined in development of Appendix A
E = Constant defined in development of Appendix A
f = Fraction of total reactor heat transferred in a boiler component
F = Cost of replacing fuel in reactor, mills/thermal kwhr
I_R = Capital cost of reactor, liquid metal loop, fuel inventory and site, \$
I_E = Capital cost of heat exchangers, \$
L = Cost of power conversion equipment such as turbine, condenser, cooling water system, and transformers, \$/kw
L/L_0 = Reflected to unreflected length of reactor core
p = Plant capacity factors, hours per year
q = Reactor thermal power, kw or Btu/hr
r = Amortization rate, 1/year, or %/year
t_1 = Primary coolant temperature entering reactor, F
t_2 = Primary coolant temperature leaving the reactor, mixed, F
t_f = Maximum fuel element temperature, F
U = Overall heat transfer coefficient either in heat exchanger or in fuel element, Btu/(hr)(sq ft)(deg F)
W = Coolant flow rate, lb/hr
α = $\frac{\text{Heat to coolant from moderator and fuel element}}{\text{Heat to coolant from fuel element}}$
β = Heat exchanger parameter for boiler $\beta = \frac{C_1 C_2 r_b}{U_{ev} I_R r_R}$
β_i = Parameter for intermediate heat exchanger $\beta_i = \frac{C_4 C_2 r_i}{U_i I_R r_R}$
Γ = Fuel replacement parameter $\Gamma = \frac{C_2\, Fp}{I_R r_R}$
η = Net power plant efficiency
θ = Mean temperature difference, deg F
λ_c = Reactor coolant parameter, $\lambda_c = \frac{WC}{\alpha UA}$
σ = Average temperature difference in boilers, deg F

$$\sigma = \frac{f_{ec}}{\theta_{ec}} + \frac{f_{ev}}{\theta_{ev}} + \frac{2f_{sh}}{\theta_{sh}}$$

Subscripts

b = Boiler
ec = Economizer
ev = Evaporator
E = Heat exchangers
i = Intermediate heat exchanger
R = Reactor, liquid metal system, fuel inventory, and site

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Philadelphia Electric Projects World's Most Efficient Central Station

PLANS to construct a power-generating station that will establish new "highs" for efficiency, steam pressure and temperature were announced on August 28 by R. G. Rincliffe, president of Philadelphia Electric Company.

"Representing an initial investment of some $45 million, the new power plant, which will be located at a point yet to be determined, will serve the rapidly growing Delaware Valley," Mr. Rincliffe stated. "The new plant," he said, "will add more than 10 per cent to the present generating capacity of Philadelphia Electric Company."

The 275,000-kw turbine-generator unit, the largest ever ordered, will be built by the Westinghouse Electric Corp. The steam generator for the plant will be built by Combustion Engineering, Inc., and will supply steam to the turbine at the highest steam pressure and temperature of any existing or projected power plant in the world, 5000 psi and 1200 F, although initial operation will be at 1150 F.

In discussing the unique engineering features of this new unit, K. M. Irwin, Philadelphia Electric vice president in charge of engineering stated that the expected plant heat rate for steam conditions of 5000 psi and 1150 F would be 8400 Btu per kwhr, some 600 Btu less than the heat rate for the most efficient existing power station.

The tandem-compound, four-cylinder turbine will operate at 3600 rpm, utilizing triple-flow exhaust to the condenser and double reheat. Both reheats will be to 1050 F.

All elements of the turbine except the super-pressure element are of conventional design using ferritic materials. The first, or super-pressure, element will be designed for initial steam conditions of 5000 psi and 1200 F, exhausting at approximately 2400 psi. The second element combines both high-pressure and first reheat pressure turbines in a common casing. The third element combines intermediate pressure and single-flow low-pressure turbine in one casing, and the final element is a conventional double-flow pressure turbine exhausting to the condenser at 1.5 in. Hg absolute pressure.

Steam will be condensed in a 105,000 sq ft, single-pass, radial-flow Westinghouse condenser. Two pumps, each of 75,000 gpm capacity, will provide cooling water to condense the steam. Special precautions will be taken to minimize leakage of circulating water into the condensate system. Nine stages of feedwater heating are contemplated, giving a temperature of approximately 565 F boiler feed supply. Westinghouse feedwater heaters of approximately 31,000 sq ft will heat the feedwater.

The generator for the plant will be rated at 352,000 kva, three-phase, 60 cycles, 24,000 volts, 3600 rpm. It will be self-ventilated with shaft-mounted fans, and will employ hydrogen inner-cooling of rotor and stator conductors. Hydrogen pressure will be 45 psi. Without the use of inner-cooled conductors, developed by Westinghouse engineers in 1950, it would be impossible to build a 3600 rpm generator of this size. Separate motor-driven d-c generators will provide excitation for the main generator. Magnetic amplifiers will be used to regulate terminal voltage of the generator.

The boiler will be a C-E Sulzer Monotube steam generator of the super-pressure, "once-through" type and will employ the principle of forced circulation. It will be a twin-furnace design with tangential firing and reheat steam temperature control by means of tilting burners. The overall arrangement corresponds in general to that employed in many of the large boilers that Combustion Engineering has designed for utility service. It marks a natural evolution in design to meet the requirements of super-critical pressure.

Maximum design steam conditions for the boiler are 6000 psi and 1200 F. At rated load, primary steam flow will be 1,540,000 lb per hr. In the first stage of reheat, steam at 1050 psi will be reheated to 1050 F. Conditions for the second stage of reheat will be 250 psi, 1050 F.

Of the total heat transferred in the boiler, more than 65 per cent will be absorbed in the superheater and the two reheaters. To accomplish this, radiant-wall type superheating surface will supplement the conventional suspended superheater and reheater sections. Three regenerative-type air preheaters are to be installed.

There will be about 150 miles of tubing, much of it 1$^1/_8$ in. diameter. Alloy steels will be employed in approximately 80 per cent of the tubing.

American license rights to Sulzer designs and patents were acquired last year by Combustion from Sulzer Bros., Ltd. of Winterthur, Switzerland, following several years of investigation of European development in the field of high steam pressures and particularly of "once-through" types of boilers. Sulzer Bros. developed this type of boiler some years ago and has made a large number of high-pressure installations in Europe.

BOILER ROOM of the S. S. World Glory, largest tanker ever built in the United States, features well-planned, spacious firing aisle with Combustion Engineering vertical superheater boilers supplying steam for this giant cargo vessel. The tanker, when full, can transport over 16 million gallons of gasoline

REVIEW OF NEW BOOKS

Any of the books here reviewed may be secured through Combustion Publishing Company, Inc., 200 Madison Ave., N. Y.

Production of High-Btu Oil Gases from Crude Shell Oils

By E. B. Schultz, Jr., J. J. Guyer and H. R. Linden

Recent development of processes for the commercial extraction of oil from the nation's great deposits of oil shale (containing an estimated recoverable 500 billion barrels) has led to an investigation of the use of shale oil in the production of high-Btu oil gases. The work was sponsored by the Gas Production Research Committee of the American Gas Association.

The oil gas yields from shale oil were found to be approximately the same as those obtained from petroleum oils of equivalent carbon-hydrogen ratio, and, when scrubbed and blended with inerts to the desired heating value and specific gravity, had equal or greater substitute ability for high-methane natural gas than petroleum oil gases of the same heating value.

The 24-page paper-bound interim report may be obtained for $2.50 from the Institute of Gas Technology, 17 West 34th Street, Chicago 16, Ill.

Heat Transmission Third Edition

By William H. McAdams

Practically all engineers concerned with heat transfer design problems will welcome this Third Edition of what has become a classic text and reference on the subject of heat transmission. The new edition, like its predecessors, is sponsored by the Committee on Heat Transmission of the National Research Council. Prof. McAdams has critically reviewed the material in the earlier editions so that the present one is representative of the current state of the art. Much the same arrangement of the subject matter has been kept, but certain of the earlier references have been omitted where recent data of greater accuracy are available. The chapter on radiant-heat transmission has been revised and expanded by Prof. H. C. Hottel who, like the author, is a member of the faculty at the Massachusetts Institute of Technology.

For those unfamiliar with the earlier editions, a listing of some of the subjects covered by chapter headings will give an idea of the scope of the book. These include steady and transient conduction; radiant-heat transmission; natural and forced convection; heating and cooling inside and outside tubes; compact exchangers, packed and fluidized systems; high-velocity flow; condensing vapors and boiling liquids; and applications to design.

The author is especially careful to list and clarify nomenclature at the beginning of chapters and to include many typical problems, some of which are worked out in detail. In the appendix there are 45 pages of useful tables and conversion charts. One of the most valuable sections is the 30-page bibliography and author index, listed by chapter with page references, which includes data released through 1952.

There are 532 pages in the Third Edition which sells for $8.50.

Introduction to Nuclear Engineering

By R. L. Murray

Based on a series of lectures given by the author in the undergraduate and graduate curricula in nuclear engineering at North Carolina State College, this text is probably the first of many that will find use in training future engineers in this subject matter. It is intended to provide junior or senior students with a perspective of the nuclear field and includes typical engineering problems that may be encountered. As a teaching approach, the author first presents the qualitative concept, then an elementary mathematical analysis and finally a review of the applications and significance of the material. Practicing engineers will also find the book to be quite understandable and a helpful reference work.

The text begins with a review of modern atomic and nuclear physics, followed by consideration of neutrons, fission, isotope separation and plutonium production. Six chapters are devoted to nuclear reactors, including basic principles, descriptions of the water boiler and swimming pool reactors, methods of reactor start-up and operation, materials of reactor construction, and some of the elements for designing enriched and natural-uranium reactors. Consideration is given to such subjects as heat transfer and fluid flow, radiation hazards, shielding, radioactive waste disposal, instrumentation, neutron experiments and uses of isotopes. The concluding two chapters take up applications of nuclear energy to propulsion and for stationary power

generation. A set of problems and a short bibliography accompany most of the chapters.

It should be understood that this is a text which covers the comparatively new field of nuclear engineering in a survey form. It does not go into any subject very intensively but does provide a broad overall account of unclassified nuclear technology.

The text contains 418 pages and sells for $9.35.

ASTM Specifications for Steel Piping Materials

The 1954 edition of this compilation sponsored by ASTM Committee A-1 on Steel contains in their latest approved form the 53 widely used ASTM specifications for carbon-steel and alloy-steel pipe and tubing, including stainless.

Materials covered include: pipe used to convey liquids, vapors and gases at normal and elevated temperatures; boiler, superheater and miscellaneous tubes; still tubes for refinery service; heat-exchanger and condenser tubes. To make the volume more complete there are also included specifications for the following materials used in pipe and related installations: castings; forgings and welding fittings; bolts and nuts. The ASTM standard classification of austenite grain size in steels (E 19) with two sets of charts; also the American Standards covering wrought steel and wrought iron pipe (B 36.10) and stainless steel pipe (B 36.19) are a part of the book.

In this special compilation, 22 of the specifications included in the previous edition have been revised; of this number 17 are tentatives and 5 are standards. A new specification covers ferritic alloy-steel forged and bored pipe for high-temperature service.

Now in its tenth edition, the paper-bound publication contains 370 pages and sells for $3.75.

Air Pollution Abatement Manual

Starting in 1951 the Manufacturing Chemists' Association, Inc., began publishing a series of paper-bound pamphlets making up an "Air Pollution Abatement Manual." With the recent publication of Chapter 2 which is entitled "Terminology and Selected Data," the manual is now complete. C. A. Gosline of E. I. du Pont de Nemours & Co. served as editor for the complete work.

Chapter 1, by J. M. Gillet, presents an introduction to the subject, describes the historical and recent developments, and discusses industry's responsibility for air pollution abatement. Chapter 2, by W. W. Hodge, gives selected terminology, physical data, nomographs,

and other similar information useful in this field. Chapter 3, by R. J. Bulkley, presents the problem from the aspect of dealing with the public, the plant employees, and governmental agencies. Chapter 4, by F. L. Seamans, states the fundamental bases for sound legislation and outlines the main requirements of existing local and state laws. Chapter 5, by E.M. Adams, cites the physiological effects that may be caused by air pollutants. Chapter 6, by P. L. Magill, shows how to organize a sampling program and exhibits numerous types of instruments for procuring the proper samples for subsequent analysis. Chapter 7, by L. V. Cralley, develops ways to analyze the samples collected, and states limitations on the various analytical methods. Chapter 8, by E. N. Helmers, discusses the spread of air pollutants in the atmosphere and how the rate of diffusion can be anticipated. Chapter 9, by C. E. Lapple, describes how to use various types of equipment to collect smoke, dust, mists, fumes, or sprays. Chapter 10, by R. J. Jenny, presents the corollary picture for scrubbing gases and vapors from stack effluents. Chapter 11, by L. L. Falk, develops the statistical approach to evaluating data such as may be collected in surveys, stack sampling, etc. Chapter 12, by G. F. Jenkins, is a complete bibliography of the field of air pollution and was compiled from several separate outstanding bibliographies recently assembled.

The manual is one of the most thorough and comprehensive publications covering the many aspects of air pollution. It should have considerable value both as a reference guide and as a source of information for current problems.

The price for the complete manual, including a paper binder, is $6. It may be obtained from The Manufacturing Chemists' Association, Inc., 1625 Eye St., N. W., Washington 6, D.C.

NEW CATALOGS AND BULLETINS

Any of these may be secured by writing Combustion Publishing Company, 200 Madison Avenue, New York 16, N. Y.

Valve Servicing

A 4-page bulletin, No. 531, just published by the Edwards Valves, Inc., pictures a thirty minute service operation for welded-bonnet, integral-seat valves and, in addition, gives a blueprint for making the simple tools required, so that the valves need not be removed from the line.

Electric Heaters

Heating problems for heavy oils and other viscous liquids in tanks and pipes can be helped by a study of the 4-page Bulletin 202 on tubular electric heaters prepared by the Turbine Equipment Co., Hynes Electric Heating Div. The characteristics of electric heating are furnished as well as a comparison with steam in these same services.

Flow Handbook

A complete manual covering Rotameter applications, size selection, design and materials data, flow correction, operating and maintenance instructions are given in a Flow Handbook now being compiled by Brooks Rotameter Co. The handbook now numbers 225 pages and comprises six chapters. Each issue supplied is serial numbered and registered in the owner's name so supplementary data can be added as it becomes available. Bulletin No. 100 covers the details and gives the price of the Handbook.

Steam Traps

Complete line of the manufacturer's steam traps are given in a 4-page bulletin, No. 154, released by The V. D. Anderson Co. In addition technical data, such as specifications, capacities, sizes, pressures, weights are given for all traps as well as a discussion of their construction. Information on strainers is also included.

Pyrometers

The pertinent facts about pyrometry in general industry are reported to be given in Bulletin 4371, a 6-page release put out by the Illinois Testing Laboratories, Inc. The publication claims thermoelectric pyrometers prove the most economical testing devices for temperatures beyond 1000 F. Further, pyrometers are held to be versatile as well as practical.

Compression Still

The operating principles, economy of production, outstanding design features of compression stills for producing industrially usable water from contaminated supplies are included in the new Bulletin No. CP-10 of the Badger Mfg. Co. Standard units range in capacity from 15 gal per hr to 10,000 gal per hr.

High-Temperature Paints

Descriptions and technical data on new high-heat-resisting finishes for temperatures as high as 1600 F are contained in a 4-page bulletin, No. 5311, released by General Paint Corp. Physical properties, various applications and the economic advantages of special finishes for hot metal surfaces are given.

Valve Catalog

Selection of the proper regulating or relief valve from the line manufactured by Schade Valve Mfg. Co. is greatly simplified by use of the new 24-page Catalog 207 now available. A descriptive index is furnished and considerable detailed information supplied to help in judging the factors involved such as type of service—air, steam or water—initial pressure, reduced pressure, temperature and capacity required.

Portable Temperature Indicators

A new 8-page bulletin, A-303, published by the Foxboro Co. describes two portable temperature indicators, the potentiometer indicator and the resistance thermometer. These instruments are used for periodic temperature tests to spot impending troubles. Operating adjustments, design features, test circuits, measuring elements, and instrument specifications are described in detail.

Fan Catalog

Heavy-duty fans, Series 200, for induced-draft service featuring forwardly-curved blades designed for public utility and industrial steam

power plants are covered in the 8-page Catalog 1380 now available from the Sturtevant Division of Westinghouse Electric Corp. A graph of certified horsepower, efficiency and pressure rating of the new blade design is presented and factors contributing to these ratings are discussed.

Power Transmission

The company's line of variable speed pulleys, wide V-belts, sheaves, motor bases, countershafts and Select-O-Speed transmission Equipment released by the Lovejoy Flexible Coupling Co.

Close-Coupled Pumps

Construction features of Allis-Chalmers supporting-adapter type, close-coupled general-purpose pumps in capacities up to 2500 gpm at heads to 550 ft are described and shown in a 6-page bulletin, No. 52B6083A, released by the company. Alternate sealing arrangements are listed, and there is a table of dimensions.

Flow Regulator

Self-contained flow regulating device for clean gas-free liquids constitutes the subject matter for a 4-page Catalog 10-F-70 made available by the Fischer & Porter Co. This device requires no compressed air, electricity or other external power supply or operating medium. It is said to fall in the category between pneumatic or electric automatic equipment and the manually-operated valve.

Power Scrapers

An 8-page catalog, No. 551, describes the Twin-Power scraper of the Euclid Div. of General Motors Corp. It hauls loads of 18 cu yd struck, 21 cu yd at 3:1 slope and 24 cu yd at a 1:1 slope at speeds up to 31 mph and has the ability to self-load most materials. For coal-handling and stockpiling it has proved of particular value.

Level and Pressure Control

A time impulse transmission system, the Chronoflo Telemeter, for control of level in reservoirs and elevated and ground storage, or pressure in pump discharge lines or steam distribution main is fully described in the 8-page Bulletin 230-K10 of the Builders-Providence, Inc. Descriptions and illustrations of transmitters and receivers and diagrams of installation arrangements are included.

Blowoff Valves

A redesigned line of blowoff valves with flanged or welding ends and bolted bonnets for 300,400–600, 900–1500 psi classes and welded bonnet blowoff valves with welding ends for 1500 and 2500 psi classes comprise the material in the 18-page Catalog 12-D1 just published by Edward Valves, Inc. There are ample installation photographs, descriptive line drawings and cutaway views. Tables are given on material specifications, on flanged and welding end details as well as valve descriptions.

Water Treatment

New informational bulletin, 28X-7501A, now available from the Allis-Chalmers Mfg. Co., gives 6 pages of data on water treatment for cooling towers. The bulletin discusses types of cooling systems together with problems such as corrosion of metal surfaces, inorganic scaling, algae and bacterial slime, and delignification of the wood in the tower.

Ion Exchange

The three major classifications of industrial water treatment based on ion exchange—softening, dealkalinization, and deionization—form the subject matter of the 24-page, Rohm & Haas Co. booklet entitled "If You Use Water." Major process variations are given, the different advantages each has and the possible applications in industry.

Air Motor Operators

Positioning dampers, burners, and valves with rotory shafts, such as butterfly and adjustable part valves, can be accomplished with the Air-O-Motor operator now being built by the Industrial Div., Minneapolis-Honeywell Regulator Co. and featured in their 8-page Bulletin 414-1. These operators come in spring and spring-

less types and the bulletin fully describes each, gives their operating characteristics as well as specifications.

Expansion Joints

Designed and engineered to meet industrial needs for low-pressure and vacuum service joints, Sola-Flex convoluted couplings are featured in a catalog No. 55, a 16-page publication furnished by the Solar Aircraft Co. The catalog includes ten pages of tables giving complete data on each size and type of coupling, along with dimensional diagrams and formulas to calculate coupling movements.

Combustion Control

New 4-page bulletin, No. SA 11-50, covers a Robot-Eye, electronic combustion control especially designed for the rotary cup burner and one that may be used in manual, semi-automatic or fully automatic combustion control systems.

Plant Modernization

Complex modernization and plant expansion problems, approached in a detailed step by step procedure, constitute the subject matter of a 16-page, Walter Kidde Constructors, Inc., bulletin entitled "Basic Planning—Plant Modernization and Expansion" recently released. This material, second of a series known as aids to management, is well illustrated and sectionalized.

Amplidyne Systems

How and where amplidyne systems are used to advantage can be found in the two-color, 24-page booklet, GEA-4053, The Amplidyne. The publication includes multi-color cross sections, circuit diagrams, charts, and photographs and a step-by-step explanation of the electrical principles behind the amplidyne.

Voltage Regulator

Engineering details of the Allis-Chalmers Mfg. Co.'s transformer type 5/8 per cent=steps feeder voltage regulators, Type AFR, make up the 16-page Bulletin 01B6056D recently released. The advantages of unit-type construction are set forth as well as the features of the quick-breaking, tap-changing mechanism.

Chemical Cleaning

The now well-established service of chemical cleaning of industrial equipment makes up the subject matter of a 4-page bulletin by Dowell, Inc. and bearing the title "Chemical Cleaning Service for Industrial Equipment."

Personals

Warren L. MacDonald has been appointed District Manager of the Los Angeles office of Combustion Engineering, Inc. A graduate of the University of Oklahoma, where he was awarded an electrical engineering degree in 1946, Mr. MacDonald served as a project engineer for The Fluor Corp., Ltd., until June 1951, when he joined the sales department of Combustion Engineering, Inc. in the Los Angeles office.

C. B. Campbell, consulting engineer for the steam division of Westinghouse Electric Corp., has been appointed chief engineer for the division according to an announcement by W. C. Rowland, vice president.

The Engineering Societies of New England recently presented the New England Award for 1954 to **William F. Ryan,** engineering manager of Stone & Webster Engrg. Corp.

Samuel Kameros and **John Tesorio** have become partners in the engineering firm of Carlson & Sweatt.

Carl S. Reed has announced his retirement as chairman of the board of directors of Lummus Co., a post he held since 1949.

Several appointments to administrative positions on the staff of the U. S. Atomic Energy Commission were announced by **K. D. Nichols,** general manager. They were: **Alfonso Tammaro,** manager of the Chicago operations office, to assistant general manager for research and industrial development; **E. J. Bloch,** director of the division of construction and supply, to director of the production division; **J. A. Derry,** assistant director of the production division, to director of the division of construction and supply; **J. J. Flaherty,** field manager, San Francisco office, to manager of the Chicago operations office; **Dr. Frank K. Pittman,** assistant director of operations in the production division, to deputy director of this same division; **W. K. Maher,** assistant director for construction and engineering in the division of construction and supply, to deputy director of the division; **George F. Quinn,** chief, pile products branch, production division, to assistant director for operations, production division **W. K. Davis,** manager of the research division of California Research and Development Co., to assistant director, Technical, of the reactor development division; **R. E. Hollingsworth,** chief of administration, division of production, to assistant director of the division.

New Equipment

Vacuum Pump

A rotary positive displacement pump equipped with mechanical shaft seals and known as Model MB has recently been announced by the Kinney Mfg. Div., New York Air Brake Co., Boston, Mass., to serve in the low-pressure range where single-stage vacuum pumps show poor volumetric efficiency.

As a vacuum booster pump the unit is especially designed to exhaust into the manufacturer's single-stage pump acting as a second stage or backing element. The combined unit is said to have a far wider high vacuum range with lower power consumption than possible with commonly employed mechanical principles.

Bronze Valves

Complete line of bronze valves equipped with Coradur stems are said by Reading-Pratt & Cady Valve Div. Reading, Pa., to be the answer to corrosion and dezincification problems. The material, Coradur, is composed of 91 per cent copper, 7 per cent aluminum, 2 per cent silicon. It weighs 10 per cent lighter than naval brass yet offers high tensile strength (over 95,000 psi) and about twice the hardness of naval brass.

Spacer Sleeve

A one-piece high tensile sleeve of cast iron manufactured by Rollway Bearing Co., Inc., Syracuse, N. Y., replaces steel liner spacer sleeves with their bronze inserts in the company's SDT precision thrust roller bearing. This type thrust bearing is used in worm gear assemblies or reducers where direction of thrust is frequently reversed. In this new thrust bearing design one plate rotates and the other remains stationary. When the load reverses the plates reverse their action. The cast iron spacer has a uniform coefficient of expansion and wears well.

Pneumatic Instruments

A new 3-part, pneumatically operated instrument sytem, the Metagraphic, produced by the Bristol Co., Waterbury 20, Conn., employs separately packaged units—a transmitter, a receiver (recorder or indicator) and a controller. Each unit can be installed where it operates best to give a high flexibility of application.

These instruments measure, indicate, record and control pressure,

vacuum, temperature, liquid level, differential pressure and flow. A universal 3–15 psi air pressure signal interconnects the three units no matter what variable is transmitted.

Unit-Bus Construction

For direct connection of generators and main power transformers in a unit generation system General Electric Co.'s high-voltage switchgear department, Philadelphia, Pa., has developed a unit-supported bus of the isolated phase design that is capable of withstanding high short-circuit currents yet weighs $13^1/_2$ per cent less than present typical three-phase sections with single insulator supports. The new bus is available in lengths of three-phase sections up to 16 ft and ratings up to 10,000 amps, 14.4 to 34.5 kv.

Conductivity Cells

A series of electrolytic conductivity cells for power plant applications have been announced by the Foxboro Co., Foxboro, Mass. These units, designed for service with the manufacturer's Dynalog conductivity instruments, detect the concentration of solids dissolved in boiler feedwater, steam samples and condensate returns. The cells have constants of 1, 0.1 and 0.01 and are available in two types, both designed for insertion in a pipe line or a tank. One type includes a valve and fittings to provide for removal of the cell under pressure. Cell electrodes are carbon, and require no platinization.

Sampling Hopper

Perfectly uniform and representative sample of 5, 10, 15 or 20 per cent of the amount of coal fed is obtainable with a newly designed automatic sampling hopper just announced by the American Pulverizer Co., 1249 Macklind Ave., St. Louis, Mo. The percentage of sample is quickly and, the manufacturer claims, accurately controlled by a simple lever and calibrated quadrant.

Oil Burner

Especially designed oil burner, the 4-in. Hev-E-Oil, has been built by the Cleaver-Brooks Co., 326 E. Keefe Ave., Milwaukee, Wis. for commercial, industrial and institutional installations requiring better than 6000 gallons of oil per year. It is a low-pressure, air-atomizing type, with all electric ignition and claimed to burn No. 4 and No. 5 oils without preheating The unit comes completely packaged, completely wired and ready for service lines.

Aluminum Piping

An integrally extruded, steam-traced aluminum pipe manufactured by Aluminum Co. of America, 1501 Alcoa Bldg., Pittsburgh 19, Pa., is made up as a single unit from Alcoa 35-F aluminum alloy. The new product is slightly oval in cross-section because of the crescent-shaped steam passage adjacent to the product line and is now available in pipe dimensions of 2-in., schedule 40 pipe. Steam flows through the small section and the sluggish process fluid through the larger section. By use of this integral design as against an external steam jacket or steam tube to apply the necessary heat considerable savings are reported in material, in insulation and in labor for a given installation.

Induction Motors

Full protection against moisture and corrosion is provided in a new line of weather-proofed, squirrel-cage induction motors called Sil-Clad, being built by the Electric Machinery Mfg. Co., Minneapolis 13, Minn. These motors, offered in ratings of 250 hp and larger, feature complete silicone insulation on the motor winding, silicone enamel backed on all exposed metal parts of the motor and stainless steel on parts subject to abrasion. The mechanical construction minimizes the entrance of air-borne dirt and particles.

Fluid Metering

A new device, known as the Dall flow tube, consists of a short-flanged, cylindrical body designed with an abrupt decrease in diameter, followed by a conical restriction and diverging outlet. This equipment built by Builders-Providence, Inc. division of B.I.F. Industries, Inc., 345 Harris Ave., Providence, R. I., is designed for use with gases and liquids carrying no settleable solids. It is said to have the lowest permanent head loss of any differential producer of its type, with a reported minimum maintenance from an unobstructed flow path.

Flow Regulator

A small, pneumatically-operated control valve manufactured by the Bailey Meter Co., 1050 Ivanhoe Rd., Cleveland 10, Ohio, is said to give straight line, flow characteristics to butterfly valves, dampers and feeders regulating gas and liquid flow. A pneumatic signal actuates a positioning relay which in turn accurately positions a piston-operated drive lever arm. The different characteristic cams are supplied and may be shaped if necessary.

In Deaeration, too

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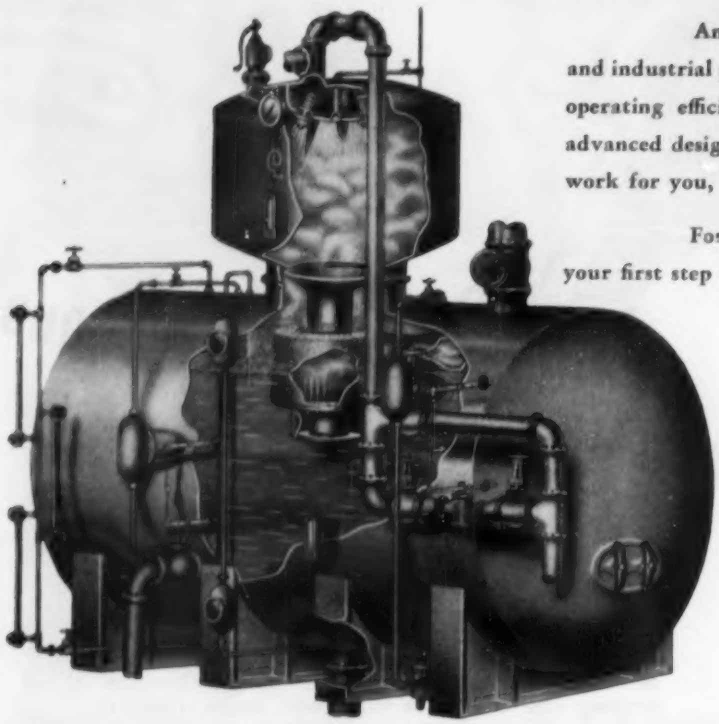
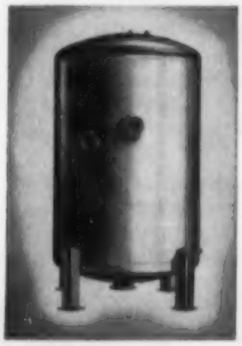


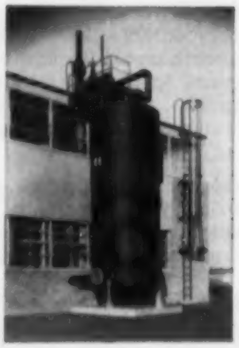
An increasing number of well known utility and industrial plants are using Belco equipment to increase operating efficiency and decrease operating costs. Belco advanced design and application experience can be put to work for you, too.

For technical assistance write or call Belco — your first step to lower costs.

SPRAY TYPE — Belco Deaerator in large eastern oil refinery. Has a capacity of 300,000 lbs/hr.

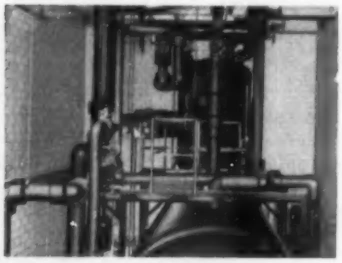


MARINE TYPE—Typical Belco marine heater furnished to shipyards. (Approved by Lloyds of London)

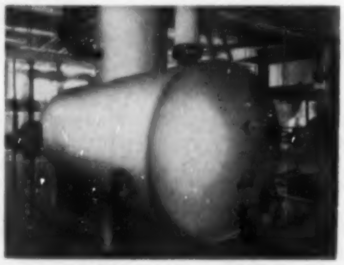


OPEN TYPE—Deaerator at large eastern pharmaceutical plant. Capacity of 80,000 lbs/hr.

VACUUM TYPE — Unit shipped set-up to midwestern utility. Has 150,000 lbs/hr capacity.



SPRAY TRAY TYPE — Belco Deaerator at New York State institution boiler house. Capacity 120,000 lbs/hr.



TRAY TYPE — Belco Deaerator at southern municipality. Has a capacity of 125,000 lbs/hr.

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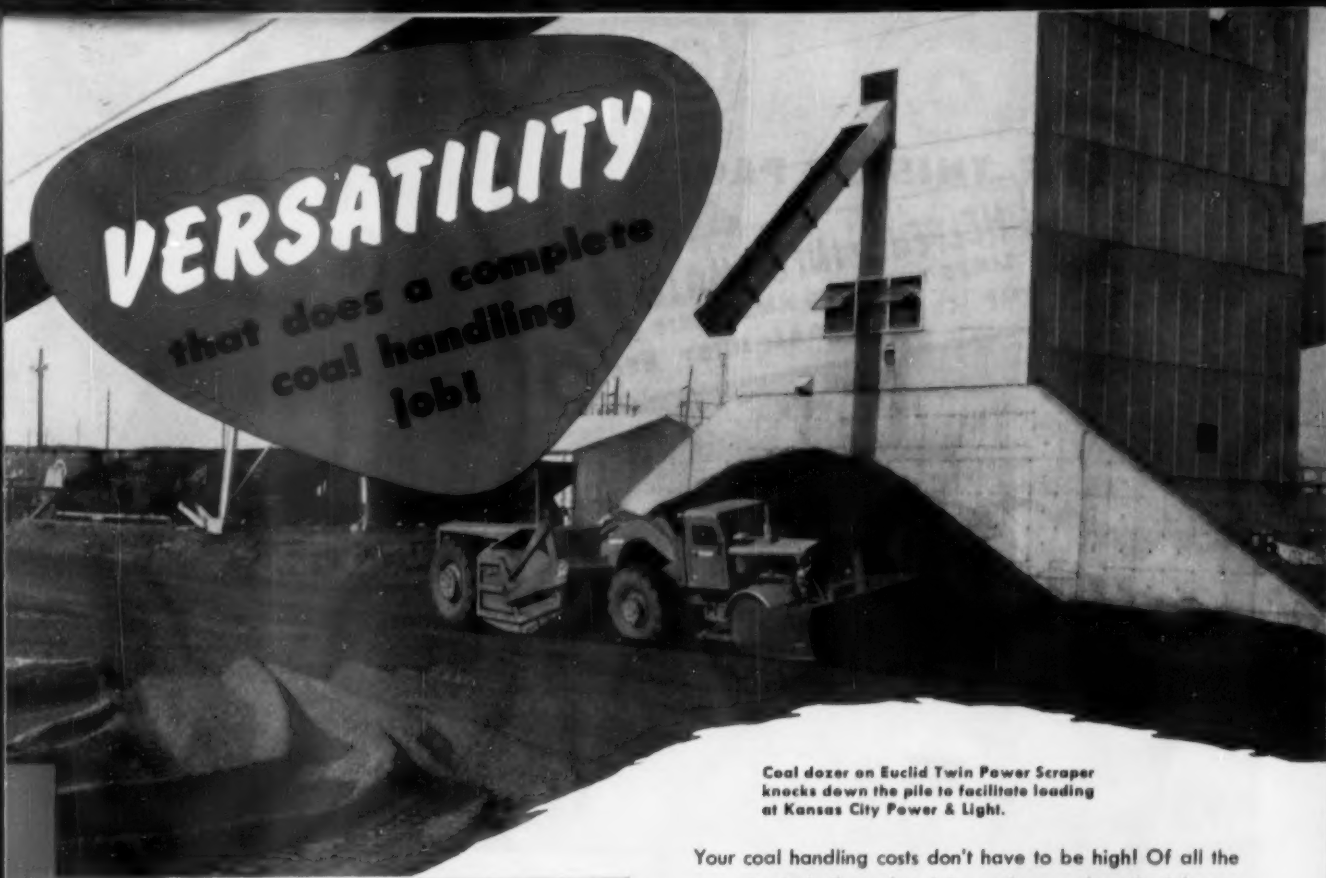

Coal dozer on Euclid Twin Power Scraper knocks down the pile to facilitate loading at Kansas City Power & Light.

"Twin" Scraper dumps its big load . . . spreads . . . and compacts on the fly!

The "Euc" maintains a well-drained, compacted pile . . . self loads for storage or haul to the plant.

Your coal handling costs don't have to be high! Of all the ways to stockpile and reclaim coal, none does the job as efficiently and completely as the Euclid Twin-Power Scraper.

The "Twin" is completely self-loading in loose, compacted, wet or frozen coal. It builds, raises or extends a well drained and compacted stockpile . . . carries big loads at speeds up to 30 m.p.h. Using Euclid Twin-Power Scrapers for coal handling is more economical and a great deal more flexible than permanent cranes and conveyors — from both original investment and operating standpoints. The "Twin" method costs less per ton handled — as compared to other equipment — because of the speed, capacity and versatility of these "Eucs".

Kansas City Power & Light Co. uses a Euclid "Twin" at its big Hawthorn station and is well satisfied with the high production and low maintenance obtained. Installation of a coal dozer further increases the scraper's versatility by enabling the "Euc" to dress edges of the stockpile, knock down loose, steep piles at the delivery area, and clean up at the dumping hoppers.

Many other industrial plants and public utilities are cutting their coal handling costs with Euclid Twin-Power Scrapers. There's a good chance your Euclid Distributor can show you the way to lower costs, too!

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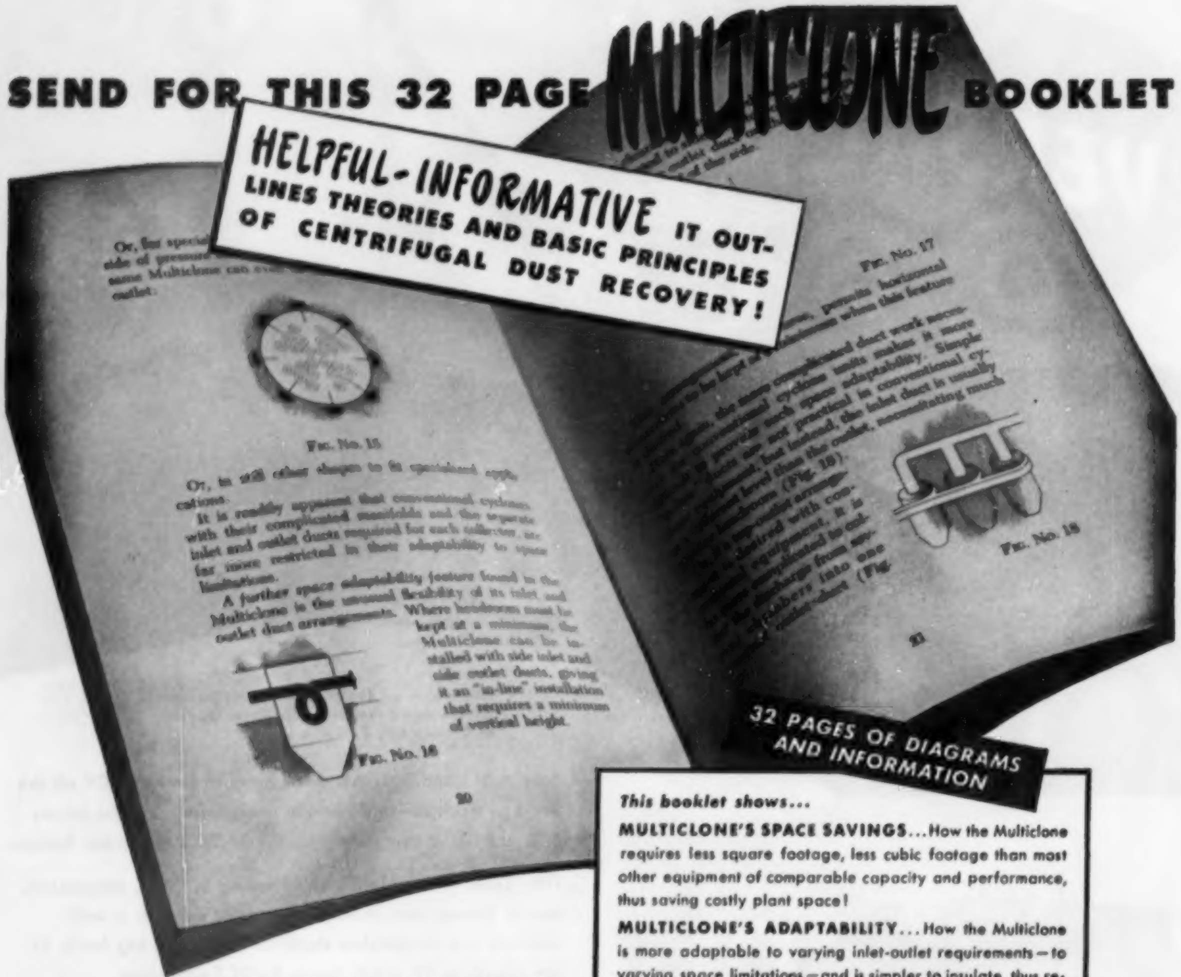

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NO MATTER whether you are now using mechanical dust recovery equipment or are planning the installation of such equipment at some future date, here is a booklet that is full of helpful and valuable information on centrifugal dust recovery. It not only explains the basic methods and principles involved, but also shows the important differences between small and large diameter separating tubes, shows how to simplify your duct work and reduce installation costs, and outlines many other important factors to be considered in selecting mechanical dust recovery equipment.

In addition, this informative booklet illustrates and explains how MULTICLONE'S unique *vane* design is fundamentally different...how it makes possible greater compactness, simpler installation, high recovery of the small particles as well as the medium and coarser ones, and many other facts on MULTICLONE advanced design.

A limited supply of these booklets is available for free distribution to those interested in mechanical recovery equipment and methods. Write for your copy today.

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Advertisers' Index

(Continued on page 93)

More Power TO FLORIDA'S VACATIONLAND

Florida Power and Light Co. will increase capability of CUTLER plant to 375 Mw...

FLORIDA POWER & LIGHT CO. CUTLER PLANT, Design and construction supervision by EBASCO SERVICES, INC.

and 135,000 kw Unit #6 will be served by an I-R 65,000 sq. ft. surface condenser ***only 14′ 8″ high!***

To keep pace with the ever-growing load demands of Miami and its surrounding resort area, Florida Power and Light Company is engaged in a construction program that will bring its total generating capability to over one-million kilowatts by 1956.

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As illustrated above, the condenser for the sixth unit at Cutler shows what can be done to reduce basement height and still retain the advantages of conventional condenser arrangement. This 65,000 sq. ft. unit only 14′ 8″ high embodies the same basic design features that have earned Ingersoll-Rand surface condensers their enviable reputation for performance.

Flexibility in design, as exemplified by this installation, is our forte. Your station layout problems can be met in a similarly efficient, economical manner if you'll call in Ingersoll-Rand surface condenser specialists.

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With RCA's new water-cooled window—you maintain continuous observation of flame conditions and ignition—*at the control panel*—24 hours a day. High-detail picture eliminates the need for periodic observation of furnace and checking burner operation.

Water-cooled window can be installed at top of furnace to observe tangential firing—in side of furnace to observe direct firing. High-capacity blower and pump unit can serve two windows.

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By using a high-efficiency circulating system, RCA has reduced lens temperatures at the camera below 120° F—for stable, dependable camera operation.

The RCA Industrial TV water-cooled window is a reliable tool for use by your operators for continuous remote observation of combustion conditions. RCA now offers this new revolutionary equipment as a complete, engineered package to power plants—plus installation and maintenance service.

FOR INFORMATION on RCA Industrial TV (Type ITV-5A), write Radio Corporation of America, Dept. I-188, Building 15-1, Camden, New Jersey.

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